JAMES · D · DANA

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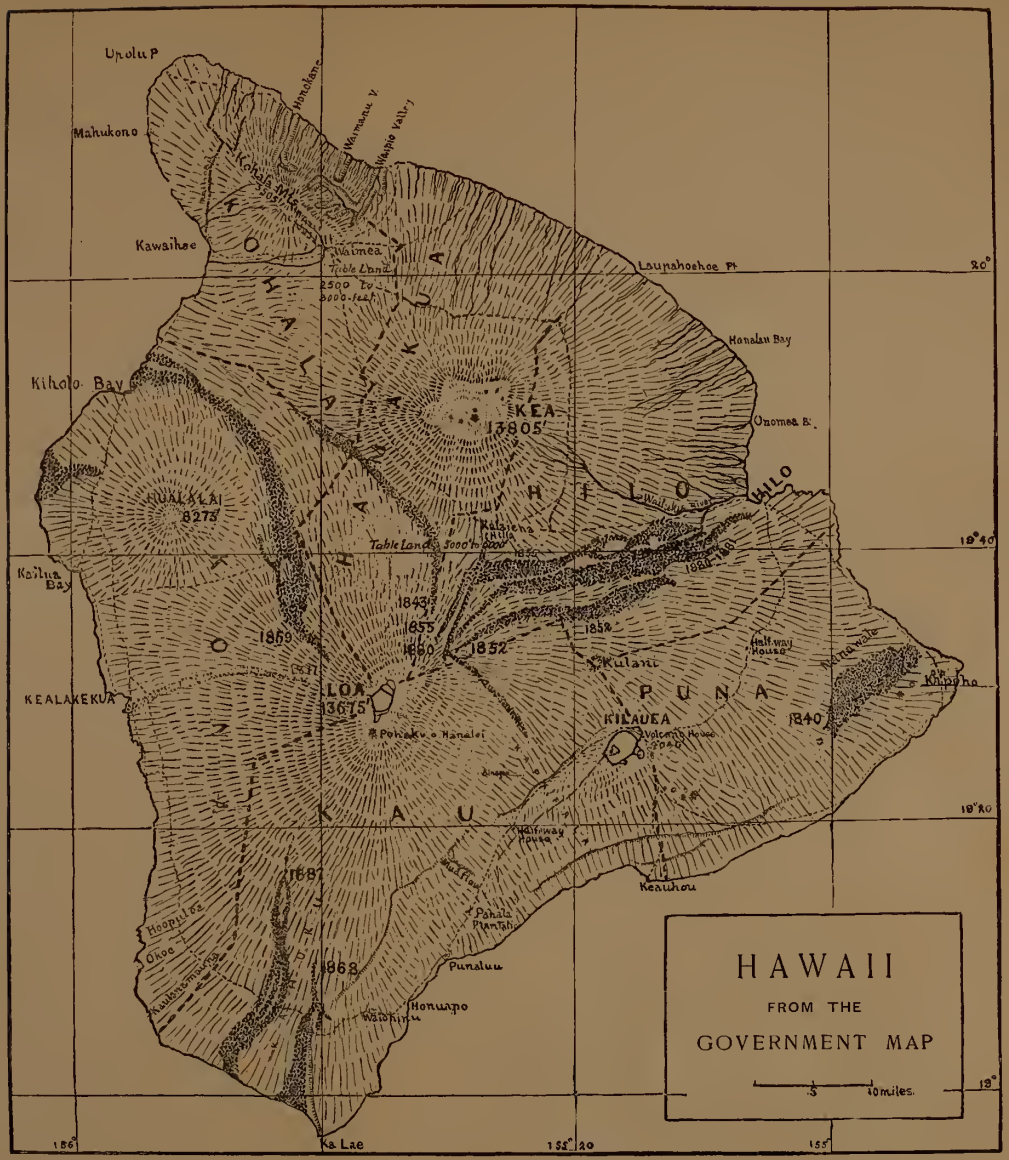
Upolu P
Mahukona
Kawaihae
Waimea
Table Land
2500 to 3000 feet
Laupahoehoe Pt
Hanalei Bay
Onomea B.
Kiholo Bay
MAUNA KEA
13805
HILO
WAILUKU
Waiakea
Kaiwiki
KUALALAI
8275
Table Land 3000 ft. above
Kailua Bay
1843
1855
1859
1860
1852
1858
Kulani
Half-way House
Kapoho
KEALAKEKUA
LOA
13675
PUNA
KILAUEA
Volcano House
4000 ft.
1840
Pohaku o Hanalei
KAU
Half-way House
1887
Keauhou
Hoopuloa
Okoe
Kaulana mauna
Pahala Plantation
1868
Punaluu
Honuapo
Waiohinu
Ka Lae
HAWAII
FROM THE
GOVERNMENT MAP
10 miles.
156°
155°20
155°
20°
19°40
19°20
19°

CHARACTERISTICS

OF

VOLCANOES,

WITH

CONTRIBUTIONS OF FACTS AND PRINCIPLES

FROM

THE HAWAIIAN ISLANDS,

INCLUDING A HISTORICAL REVIEW OF HAWAIIAN VOLCANIC ACTION FOR THE PAST SIXTY-SEVEN YEARS, A DISCUSSION OF THE RELATIONS OF VOLCANIC ISLANDS TO DEEP-SEA TOPOGRAPHY, AND A CHAPTER ON VOLCANIC-ISLAND DENUDATION.

By JAMES D. DANA.

ILLUSTRATED BY

MAPS OF THE ISLANDS; A BATHYMETRIC MAP OF THE ATLANTIC AND PACIFIC OCEANS; AND VIEWS OF CONES, CRATERS, A LAVA-CASCADE, A LAVA-FOUNTAIN, ETC.

NEW YORK:
DODD, MEAD, AND COMPANY.
1891.

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University Press:
JOHN WILSON AND SON, CAMBRIDGE.

PREFACE.

THE personal observations of the author on which this book is based commenced with the ascent of Vesuvius in 1834, and, the next month, a sight of Stromboli and a tramp after minerals on the solfataric island of Milo. They were continued in 1838 by short excursions on Madeira and one of the Cape Verds; in 1839, by studies of the extinct volcanic regions of Tahiti, Tutuila and Upolu, and the basaltic outflows and overflows of Illawarra and other parts of New South Wales. They were further extended in 1840 by observations in the Feejees, and by explorations of the active and extinct volcanoes of the Hawaiian Islands; in 1841, by observations on a crater in the coast region of Oregon, instructive though distant views of some of the lofty cones of the Cascade Range, and a brief survey of an extinct volcano on the Sacramento (now called Marysville Butte) during an overland trip from Vancouver to San Francisco; and, finally, in 1860 by a second visit to Vesuvius, and in 1887 a second to the Hawaiian Islands.

The purpose of the work is the illustration of volcanic action and principles by special reference to the facts supplied by the great, open, free-working craters of Hawaii, and by comparing and contrasting these with the corresponding features and phenomena of Vesuvius. It commences with an elementary treatise on volcanoes and volcanic action, that

the book may be a convenient manual for the geological student and also for the tourist. After these general explanations, the workings of the fires in the two active craters of Hawaii are successively set forth by means of descriptions and various illustrations; and a knowledge is thus presented of the steps in the progressing activity, the dependence of these steps on one another, and their relation to the final catastrophe. After such a study it becomes easy to apprehend the deductions which follow with regard to the methods and principles of volcanic action.

The work contains, in Part Third, an account of the topography of the Pacific basin, with a map of deep-sea Pacific and Atlantic soundings, and a discussion of the influence upon the depth of the oceans of volcanic action. Further, Part Fourth treats of denudation, or valley-making, on volcanic islands. The subject is illustrated by a map of the island of Tahiti, an admirable example of water-sculpture, and by supplementary facts from New South Wales cited from the author's "Geological Report of the Wilkes United States Exploring Expedition." Of this report only one hundred copies were ordered for the Government; and these, with an additional hundred printed at the time (fifty-one years ago) at the author's expense that it might escape oblivion, are all that were ever issued; hence some freedom in copying its nearly inaccessible pages has been thought allowable.

The pages of this volume contain many reasons why the two active craters of Hawaii should share equally with Vesuvius and Etna in the attention of investigators. Hardly three weeks distant from Europe and not two from New York, with much to be seen on the way and tropical islands growing corals and tree-ferns at the end, the route should be a common one with tourists. The

magnitude and easy access of the great craters; their proximity, while nearly ten thousand feet apart in altitude; their strange unlikeness in ordinary action, although alike in features and lavas; their unsympathizing independence; their usually quiet way of sending forth lava-streams twenty and thirty miles long, — make them a peculiarly instructive field for the student of volcanic science, as well as an attractive one for the lover of the marvellous. Even the lavas, although nothing but basalt, have afforded much that is new to science, as is shown in the chapter by my son, Prof. Edward S. Dana.

Reviewing the developments thus far made, we find that the region has already contributed many new ideas to the vulcanologist. Science has learned of volcanic activity unrestricted by altitude up to fourteen thousand feet; of the possibility of two first-class craters working simultaneously within the area of one mountain-dome, and having the loftier the more frequent and the more copious in its outflows, and neither of them ordinarily responsive to the other even when in eruption; and of the outflow of the heaviest of chrysolitic lavas at various altitudes to the very summit.

Science has learned from Hawaii more than it knew of the mobility of liquid basalt; of the consequent range in flow-angle of basalt-lavas, from the lower limit near horizontality to the verticality of a waterfall, and therefore of lava-cones of the lowest angle, and driblet-cones of all angles; of lava-lakes tossing up jets over their fiery surface like the jets of ebullition, and in other cases playing grandly in fountains hundreds of yards in height; and, consequently, of the absence from the craters of large cinder-ejections.

It has further learned of a degree of system in the changes within a crater from one epoch of eruption to a

state of readiness for another; of a subsidence, after an eruptive discharge of lava, that has carried down, hundreds of feet, a large part of a crater's floor without a loss of level in its surface; and, following this, of a slow rising of the subsided floor, chiefly through the ascensive or upthrust action of the lavas of the lava-column, and the lifting force taking advantage of the fault-planes that were made at the subsidence; and also of debris-ridges and of debris-cones, one to two hundred feet in elevation, made, by the lift, out of the talus of the pit-walls.

It has learned that pit-shaped craters are characteristic of true basalt-volcanoes, and a result of the free mobility of the lavas, whether the action in the lava-lakes within be fountain-like or boiling-like; that floating islands of solid lava may exist in the lakes; that a regular oscillation between fusion and cooling takes place at times in the thin crust of lava-lakes; that the solid lava of the margin of a lake may be re-fused, and also even the mass of a floating island, and the blocks of a debris-cone until the cone has wholly disappeared.

It has discovered that solfataric action, or that of the hot vapors in lava-caverns, may include the recrystallizing of basalt, therein making it into long, stony pipe-stem stalactites and stalagmites, having cavities lined with transparent crystals of augite and labradorite, besides octahedrons of magnetite.

It has obtained evidence, also, that the greatest of eruptions may occur without the violence or the noise of an earthquake, and without an increase of activity in the crater; that in place of an increase there may be a sudden extinction of the fires, all light and heat and vapors disappearing as soon as the discharge begins; of the greater frequency of eruptions during the wetter season

of the year; of the agency of fresh water from the rains (and snows) in the supplying of steam-power for volcanic action; of the full sufficiency of water from this source without help from the ocean, — fresh water being as good as salt for all volcano purposes; and further, of a great augmentation of the activity so produced with the increase in altitude of the working crater.

These are facts from Hawaii — and not all that might be cited — that have not yet been made out from the investigation of other volcanoes, not even the best known, Vesuvius and Etna.

But much remains to be learned from the further study of the Hawaiian volcanoes. Some of the points requiring elucidation are the following: the work in the summit-crater between its eruptions; the rate of flow of lava-streams and the extent of the tunnel-making in the flow; the maximum thickness of streams; the existence or not of fissures underneath a stream supplying lava; the temperature of the liquid lava; the constitution of the lava at the high temperatures existing beneath the surface; the depth at which vesiculation begins; the kinds of vapors or gases escaping from the vents or lakes; the solfataric action about the craters; the source of the flames observed within the area of a lava-lake; the differences between the lavas of the five Hawaiian volcanoes, — Kilauea, Loa, Kea, Hualalai, and Kohala; the difference in kind or texture of rock between the exterior of a mountain and its deep-seated interior or centre, — for the elucidation of which subject Kohala's northern gorges may possibly afford material; the difference between Loa, Kea, and Haleakala in the existence below of hollow chambers resulting from lava-discharges, — a problem which Mr. E. D. Preston has begun to solve by pendulum observations, and there is

reason to hope may continue to investigate to its complete solution; and, besides, if admitting of field study, the movements of the lavas in the great lava-columns, and the source or sources of the ascensive movement.

The geologist who is capable of investigating these subjects will find other inquiries rising as his work goes forward.

JAMES D. DANA.

NEW HAVEN, CONN.,
Feb. 12, 1890.

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CHARACTERISTICS OF VOLCANOES.

Part First.

VOLCANOES.

I. GENERAL CHARACTERS.

A VOLCANO is a mountain or hill, more or less conical in shape, which has a nearly central cavity at top, called a *crater*, and which discharges at times melted rock, called *lava*, and also vapors or gases. The lava either *flows* down this or that side of the mountain in streams, or is projected into the air to fall around the vent, or lava-source, in fragments. The cooled fragments from a *projectile* discharge are called volcanic *cinders*, but the finer part, often, volcanic *ashes;* if not cooled on the descent, they are *drops* or *driblets*.

Since the accumulation of rock-material, whether due to descending streams of lava or to projected fragments, is made around a central lava-source, or is *pericentric*[1] in deposition, the hill or mountain built up takes the form of a more or less regular cone; and a crater exists in its top because of the discharges of lava and vapor from the lava-source within or beneath it.

A volcano, as long as it is active, has thus — (1) its vapor or gaseous discharges; (2) its flowing lava-discharges; and (3) its projectile discharges.

[1] Derived from the Greek *περί, about*, and *κέντρον, a centre.*

When discharges of liquid lava take place, or unusual projectile discharges, or both together, the volcano is in *eruption*. Such eruptions result in emptying or deepening the crater. They may occur at intervals of three or four years, but often scores intervene. In the interval between eruptions, the deepened crater may be for a while wholly quiet. But sooner or later, in the active volcano, vapors begin to rise from fissures, and small lava-flows and projectile discharges take place over the bottom; and this continues, perhaps with interruptions, until ready for another outbreak.

In projectile discharges the height to which the fragments are projected into the air may be several thousands of feet during a great eruption, and hundreds or scores of feet in the interval. But in volcanoes of the Hawaiian kind the lava is ordinarily thrown to so little height that the fragments are not cooled on the descent, and no cinders or cinder-cones are made; they are thrown up like the small jets over a boiling liquid. Yet even in such volcanoes lateral and terminal cinder-cones under some circumstances are formed.

At an eruption the discharged lava may flow from the summit crater in great streams down the mountain; or, secondly, it may escape to the surface of the cone through fissures in the mountain's sides, made by the eruptive forces, and thence spread away in streams; or, thirdly, it may flow off through fissures into cavities between the old lava-streams of the mountain, or force its way between the layers, and not show itself anywhere at the surface; or, fourthly, it may only fill fissures made below by the volcanic action. Discharges of the first kind are *superfluent* discharges; those of the second, *effluent*, or out of fissures; those of the third, *interfluent*. But for the third and fourth kinds all that can commonly be said is expressed in the word *subterranean*. Superfluent discharges are probably the prevailing kind at

the commencement of a volcano, the lavas then pouring out copiously from the vent or over the brim of the crater. But at the present time the discharges are effluent, or from fissures, though often also subterranean.

The outflow from fissures may take place at any height on the mountain, from the top to the base, and also beneath the sea-level.[1] If the latter, the eruptions are *submarine;* if the former, *subaerial.*

The fissures from which outflows take place are sometimes so wide at some spots as to pour out the lavas from these places for weeks, so as thereby to make cones of lava; or if the lava ceases to flow out, they may have projectile discharges for a time and make cinder-cones. In either case a line of cones may be formed on a fissure. Such cones while in action are true volcanoes in all their characters. They are distinguished as the *lateral* cones of a volcano or volcanic mountain.[2] The extinct lateral cones of a submarine eruption often stand as islands, or make shoals, off a coast.

The regions of exhausted volcanoes, and sometimes the borders of active volcanoes, may have fissures that give out hot air, vapors, and gases in a quiet way, and that make deposits of sulphur, alum, gypsum, or other minerals about the sides of the fissures or in the soil. Such regions are called *solfataras*, from the Italian for *sulphur;* and the vapor-emitting fissures are called *fumaroles*, from the Latin for *smoke.* The heat of fumaroles may be as high as 750° F. Lava-caverns in and about craters often receive hot vapors, and have similar incrustations; and sometimes they are hung with lava-stalactites.

[1] The sources and courses of several great lava-streams are shown on Plate I. (frontispiece), the dotted belts representing the streams.

[2] Many lateral cones are shown on the map of Maui, Plate XII.

II. VOLCANIC ROCKS, GASES, AND LAVA-STREAMS.

1. Volcanic Rocks. — Lava is a general term for any rock of a lava-stream. It may be very compact, — that is, without a cellule; or it may contain air-cavities or vesicles that were made by expanding vapor while the lava was still liquid, and so be a *vesicular lava*. But vesicular lava may be very openly vesicular, like a furnace slag, and then it is *scoriaceous* lava; or it may be made chiefly of vesicles, and then it is a *scoria*, the scum or froth of the liquid lava.

Lava, on cooling rapidly, sometimes becomes glass, or has a thin glassy crust; but on cooling slowly the same material may become stone, by the conversion of glass into stony particles, which are the constituent minerals of the lava. The lighter scoria of a volcano is mostly glass. Generally, but not always, minute portions of the glass remain in the most solid lavas. By extreme slowness of cooling, such as may occur in Nature in the interior of great igneous masses or under a deep covering of rocks, the texture of lava may become coarsely crystalline, like granite or syenyte: so that, although granite has little resemblance to ordinary lava, it may be as truly an igneous rock as the lavas of Kilauea or Vesuvius, and, as Judd, Hague, Iddings, and others have shown, be part of the same eruption with scoriaceous lavas.[1]

The more common kinds of lava consist as follows: —

I. Of feldspar, as the chief ingredient.

II. Of a feldspar, with one of the two iron-bearing minerals, augite, hornblende.

I. Lavas consisting chiefly of a Feldspar. — These lavas are generally light in color and light in weight. The specific gravity is 2.5 to 2.8. The feldspar is ordinarily orthoclase or potash-feldspar.

[1] See page 314.

A common kind, breaking with a rough surface of fracture and little lustre, is called Trachyte; some black hornblende crystals are often present, and tables of feldspar called sanidin, and rarely small crystals of black or brown mica. If it contains quartz disseminated through it, visibly or not, it is named Rhyolyte (from the Greek for *to flow*) or Quartz-trachyte; when in the form of glass, it is Obsidian; when partly glassy, and therefore pitch-like or resin-like in lustre, it is Pitchstone; when a fine light scoria, Pumice.

A rock having the composition of trachyte or quartz-trachyte, but smooth, flint-like, in surface of fracture, is called Felsyte; and when coarsely crystalline, the feldspar being in crystalline grains, and the quartz in visible grains, it is called Granulyte; and the latter, when mica is present, is the common crystalline rock called Granite. A felsyte spotted with whitish feldspar crystals is a variety of Porphyry, or a *porphyritic* Felsyte.

Leucite, a potash-bearing mineral related in composition to orthoclase, is prominent in some volcanic rocks. Its crystals are twenty-four-sided garnet-like forms. It is called *leucite*, from its whitish color. A leucite-rock occurs in Wyoming, and another kind is common at Vesuvius.

II. Lavas consisting of a Feldspar and other Ingredients. — In the other common igneous rocks the feldspar may be (1) *orthoclase;* (2) *oligoclase*, which contains the alkalies, soda and lime, with more soda than lime, — or the related *andesine;* or (3) *labradorite*, which also is a soda-lime feldspar, but with more lime than soda.

1. *The Orthoclase and Hornblende or Augite Rocks.* — These rocks are Syenyte, Quartz-syenyte, Augite-syenyte, and some others which are not among the rocks of ordinary lavas.

Leucite and augite are the chief constituents of Amphigenyte (or Leucitophyre), the rock of the Vesuvian lavas just alluded to.

2. *Oligoclase Rocks.* — A common lava of this group, of light to dark gray and greenish color, is called Andesyte, from the Andes. It consists of oligoclase or andesine and hornblende. A related rock, Augite-andesyte, consists chiefly of oligoclase and augite: and where hypersthene, a mineral related to augite, replaces the latter, another variety is produced.

When a rock of the composition of andesyte has a compact or a crystalline-granular texture with none of the aspect of a lava, it is called Dioryte. Its common colors vary from whitish to greenish-black. A compact red dioryte, with part of the feldspar in small whitish crystals, is the Red Porphyry of the ancients.

3. *Labradorite Rocks.* — Basalt and Doleryte are common lavas of this group. Doleryte (or Diabase) consists of labradorite and augite, with more or less magnetite, and is a heavy dark-colored rock, with the specific gravity 2.9 to 3. Basalt is the same rock; but it contains, in addition, chrysolite (olivine), a mineral looking much like grains of green bottle-glass, with the specific gravity 2.9 to 3.2. The augite is not unfrequently in distinct black crystals, and the labradorite in white or whitish crystals. These rocks are commonly very fine-grained, and vary from compact to vesiculated, scoriaceous, and scoria. But doleryte and basalt vary also, on the other side, without change of composition, to coarsely crystalline rocks, the common kind of which is called Gabbro.

In another labradorite series the rocks consist of labradorite and hornblende. They resemble dioryte, and one kind is called Labradioryte. The green porphyry, or *oriental verd antique* of the ancients, is a handsome porphyritic variety of the rock.

Other igneous rocks have anorthite or nephelite, as prominent constituents; or they may consist chiefly of augite, hornblende, or chrysolite. On this subject of volcanic rocks reference should be made to works on petrology.

The most fusible of common lavas is doleryte or basalt, the temperature of fusion being between 2000° F. and 2500° F. Trachyte and rhyolyte are among the least fusible, and andesyte is intermediate in degree of fusibility.

A columnar or "basaltic" structure, more or less perfect, is very common in solidified lava-streams, as a result of contraction on cooling. Even the most recent lavas may exhibit it. It is most common in basaltic rocks, but occurs also in other kinds, even in obsidian or volcanic glass, as described by Iddings from the Yellowstone Park.

Tufa. — Tufa, or tuff, as its method of formation implies, is nothing but a fragmental rock of volcanic origin, — a kind of argillaceous sandstone made out of volcanic ashes usually half decomposed. Its colors vary from gray to yellow, brown, and reddish-brown. The brown and brownish-yellow colors depend on the hydrous iron-oxide ($Fe_2O_3 + Aq$) present as a result of alteration. It sometimes has a lustre almost like that of a resin, as is well exemplified at the quarry on Punchbowl, Oahu. The material, which was originally like powdered lava in composition, has been changed by the heat and moisture. The rock in this state is called *palagonite.* Besides the finer kinds, there are also coarse conglomerates among fragmental volcanic rocks.

The "cinders," or scoria, of a cinder-cone are often of a bright red color; and this is due to surface decomposition of the augite producing the red iron-oxide (hematite or red ochre, Fe_2O_3). When the decomposition goes on in the presence of moisture, the color is usually yellowish-brown, from the production of the hydrous oxide above alluded to ($Fe_2O_3 + Aq$, or limonite).

2. Vapors or Gases. — The vapors which are emitted by the liquid lavas of the volcano are at least ninety-nine per cent steam, or vapor of water. There is never any true smoke. The amount of vapor given out is large in periods

of special activity, and clouds consequently are made over the mountain in the cool air above.

Sulphurous acid (SO_2) is probably the most common of the vapors next to that of water. It has the smell of burning sulphur. Hydrogen is one of the gases that escape from the liquid lava, and its occurrence is attributed to the dissociation of the elements of water (H_2O) by the extreme heat.[1] Chlorine is emitted if sea-waters get access to the lava-column, it being supplied in that case by the common salt of the sea (NaCl); and when present, chlorides occur as incrustations on the lavas, among which are common salt, iron chloride, and others. Flames attributed to the combustion of free hydrogen have been observed.

Other gases are only very sparingly present in the liquid lavas, but occur in solfataras or fumaroles. Hydrogen sulphide (H_2S), or sulphuretted hydrogen, is sometimes detected, but not where the action is intense. Carbonic acid (CO_2) may be given out if any limestone exists beneath the volcano. Hydrochloric acid (HCl) is another of the gases from the hotter fumaroles; and nitrogen is sometimes present.

Pyrite and marcasite, iron sulphides (FeS_2), present in minute quantities in the rocks of the depths below the crater, are supposed to be the common source of the sulphur and sulphur gases.

Various deposits occur in solfataras and in caverns about volcanoes, produced by the escaping gases, of which the most common are the sulphates, — gypsum (hydrous calcium sulphate), alums (hydrous aluminum sulphate, and aluminum-sodium sulphate), glauber salt (hydrous sodium sulphate), which is common in Hawaiian hot caverns; occasionally hydrous copper sulphate or blue vitriol. The gases decompose the rocks to earth. Incrustations of sulphur are common, and occasionally large deposits are made.

[1] Fouqué, Santorin et ses Éruptions, Paris, 1879; Siemens, Monatsb. K. Preuss. Akad., 1878, from investigations at Vesuvius.

3. Lava-streams. — Lava-streams are of two kinds. (1) There is the ordinary smooth-surfaced lava of volcanoes. It is the *pahoehoe* of Hawaii, the term signifying "having a satin-like aspect." The surface of the lava shows, by the fine and coarse flow-lines over it, that it cooled as it flowed. Through one means and another the surface is usually uneven, being often wrinkled, twisted, ropy, billowy, hummocky, knobbed, and often much fractured. Plate VII. shows something of the uneven character, but not the larger irregularities. The streams have sometimes a firm glassy exterior half an inch or less in thickness. When lava overflows from a boiling lava-lake, it carries along a surface scum one to three or four inches thick, which is a glassy scoria, usually easily separable from the more solid and chief part of the lava-stream.

The crusting over of a stream while it is still flowing, owing to contact with the air above, results in the leaving of empty tunnel-like caverns, which are sometimes hung with stalactites.

(2) The other most prominent kind of lava-stream is the *aa*. The *aa* streams have no upper flow-like surface; they are beds of broken up lava, the breaking of which occurred during the flow. They consist of detached masses of irregular shapes, confusedly piled together to a height sometimes of twenty-five to forty feet above the general surface. The size of the masses is from an inch in diameter to ten feet and more. The lava is compact, usually less vesiculated than the pahoehoe, not scoriaceous; but exteriorly it is roughly cavernous, horridly jagged, with projections often a foot or more long that are bristled all over with points and angles. In some cases ragged spaces extend along planes through the large masses, like those of the exterior; but in these, as in other parts, it is evident that the agency was tearing and up-ploughing and cavity-making in its action, and not vesiculating. Occasionally (as well seen west of

Punaluu, on southern Hawaii) great slab-like masses of very compact rock, twenty feet or more long, eight feet high, and three to ten inches thick, stand vertically together, with a curving over at top, somewhat like gigantic shavings. Similar slabs are mentioned, as occurring on the Kilauea lava-stream of 1840, on page 63.

The above figure represents the features of such a stream. The title of such piles of blocks to the name of a stream would not be admitted were it not proved that they are formed during the progress of a lava-flow; that a lava-stream may change from the smooth-flowing or pahoehoe condition to the *aa*, and back again to the smooth-flowing; and that the same vent may give out at one and the same time a smooth-flowing stream in one direction and an *aa* stream in another. Lava of the *aa* kind occurs at Vesuvius, as well described by Sir William Hamilton in 1779, and later by other authors.

The *aa* streams are remarkable also for the presence of *lava-balls* of concentric structure that have been wrongly called *bombs*. These lava-balls are smoothish exteriorly, more or less rounded and bowlder-like, and vary in size from an inch or less to ten feet and more. One of them is represented in the *aa* picture, at the top to the right.

Some of these lava-balls have, *outside*, a crust of hard lava, and, *inside*, fragments of scoria or grains of chrysolite (olivine); others consist of concentric shells, hard and scori-

aceous shells alternating with one another. One on Hawaii near Punaluu was found to have a nucleus of scoria eighteen inches in diameter, and around this successively a stony shell of three inches, a scoriaceous layer of one to two inches, a stony shell of four to five inches, and then outside a rough lava shell six inches thick. One of large size, broken open on one side, had had its inside filling of scoria worked out by the natives, and so made into a small cave.[1] A common size on Hawaii is three to five feet in diameter; but one enormous lava-ball, in the *aa* field west of Punaluu, measured $24 \times 12 \times 9$ feet in its extreme dimensions, and contained at least a thousand cubic feet. Enough of its hard outer shell was pealed off to ascertain that the second layer was quite vesicular or scoriaceous, and the next layer inside hard basalt again. These Hawaiian lava-balls lie in the midst of the other blocks of the *aa* stream, proving that all had a common origin, and *that they are not projected bombs*, and hence properly not bombs at all.

The so-called "bombs" of Vesuvius have been shown independently by Dr. Johnston-Lavis, of Naples, to have had essentially the same origin.[2]

III. FORMS OF VOLCANIC CONES.

The volcanic cone or mountain takes its shape partly from the nature and condition of the material of which it is made, partly from the position of the places of outflow, and partly from the copiousness of the flow. Other causes — as subsidences and uplifts — may modify the forms; but the forms not so modified are those here considered.

If the lava were as liquid as water, cones of sensible slope

[1] American Journal of Science, 1887, 3d series, xxxiv. 364.

[2] Johnston-Lavis, in a paper on "The Fragmentary Ejectamenta of Volcanoes," in the Proceedings of the Geologists' Association, London, vol. ix. no. 6, and American Journal of Science, 1888, xxxvi. 103.

would be impossible. Lava has various grades of viscidity or liquidity; and in the most liquid stage — that which exists when the heat is at or above the fusing-point of the essential ingredients — there is still a degree of viscidity or cohesion sufficient to cause some resistance to free movement, and hence a slope in the upper surface of the flowing stream.

From this stage of most perfect mobility there may be all grades of viscidity, in consequence of partial cooling, — cooling producing incipient and finally complete solidification.

If melted beeswax were poured out on a flat surface while heated above the fusing-point, it would flow off at a very small angle; and a very copious flow would be impeded neither by cooling below against a cold surface nor above against the air. But if the temperature were below that of fusion, the liquid beeswax would be pasty, and the angle of flow or of the pitch of the upper surface would increase with decrease of temperature. Copious streams would have the smaller angle; while small streams would give increased pitch, and drops might make a vertical column.

The facts are the same in principle with lava. Basaltic lava in the state of most perfect liquidity flows at an angle much less than that of 1°, as is shown by the surfaces of the great basaltic floods in the Snake River region and others on the Pacific border slope of North America, as well as by the occurrence of a pitch of 1° and less in the lava-streams of some of the Hawaiian Islands. Copious flows — such as have occurred in the earlier discharges of a volcanic vent — may therefore make basaltic cones of 1° and less. But the flows of modern volcanoes are not ordinarily of this copious kind. The lava of an eruption is discharged in portions at intervals of hours or days or weeks, and the streams become cooled at bottom and cooled at top, so that only the interior flows on in a kind of tube or tunnel, and this, as it emerges below, takes

its chances of cooling. The streams are narrow strips down the cone. They come out usually from fissures, and at all heights between the top and the bottom. The resulting angle for a basalt-volcano becomes thereby 1° to 10°, and rises often to 90° in the driblet cone.

With the less fusible lava the cones are of steeper angle than with basalt, since the high temperature of fusion generally fails of being supplied from the depths below, and is more easily lost by cooling; and the lava therefore is commonly more or less pasty. The andesyte cones of western North and South America are 25° to 34° in slope.

Since a cone diminishes in diameter upward, a flow of lava from near the summit having like width throughout would cover a much larger part of the circumference in the upper part than in the lower. The part of the cone below would require in fact a great number of ordinary streams to make one coat over the surface. The consequence of this condition is that such discharges make the cone steeper above, and give it a concave outline. But if the flows commence for the most part a little below the summit, from an eighth to a sixth of the height, the upper part would be widened and the cone take the form of a low dome, like Mount Loa; or if the streams come from fissures in the lower part of the cone and spread beyond the base, the cone will be flattened below, and the lower part of the profile will be made concave.

The possible slopes of the sides of cinder-cones may be learned from a very simple experiment. If circles half an inch apart are described about a centre on a large card, and a slender graduated rod is inserted vertically at the centre as an axis to the figure, then by dropping dry sand, fine, coarse, and angular, in successive trials over the axis, the slope at which the different kinds of sand come to rest by gravity, under resistance from friction, may be readily obtained and compared. If enough water is mixed with the finer sand or earth to make it flow like thin mud, the angles of different-

flowing muds may be obtained. Such trials show that an angle of 40° is as great as should occur with dry cinders, unless the fragments are very irregular and light; that with fine dry sand it may be as low as 25°; and that an angle of 15° is not too small for a flowing mud, though steeper slopes may also occur.

Cinder-made cones are usually between 30° and 40° in angle; but they vary in height, breadth, and slope on the different sides, according to the direction of the prevalent winds. Alternations of cinder and lava ejections will make a cone of steeper slope than lava alone; and this may be part of the reason for the high angle of slope of the volcanic mountains of western America. Summit ejections of cinders may increase height without adding much to the mass of a mountain.

Flowing muds are made out of volcanic ashes or cinders when waters descend in torrents during copious violent projectile eruptions. The stream of mud so produced may flow off at a small angle of pitch, and make a low-angled, broad-topped cone, with a broad, saucer-like crater, — a tufa-cone. If the vent is at the sea-level or a little below it, so that the sea-water would be made to boil up by the heat of the vent and escape with the projected cinders or ashes, the mud-stream would flow directly from the interior of the crater. Punchbowl, Diamond Head, and the hills of Koko Head, figured on Plate XIV., are examples of tufa-cones.

By making an outline of a section of a cone and drawing lines parallel to the sides, the usual figure of a section of a lava-cone or cinder-cone is obtained. But as lava-streams are to a large extent strips or patches of lava over the surface, the diagram conveys a wrong impression, since it seems to imply that the cone consists of a regular series of coats. In a tufa-cone there is a slope beneath the crater, as well as down the outer surface, — a structure illustrated in the left of the Koko Head craters on Plate XIV.

Ejections of volcanic cinders or ashes from the chief vent or crater of a basalt-volcano are generally of small amount; but they may make beds a thousand feet or more thick about volcanoes of other kinds.

Non-Volcanic Igneous Ejections. — Ejections of melted rock like those of volcanoes, and of great extent, have often taken place without volcanic agency. Fissures have opened in the earth's crust and let out liquid rock, sometimes with little overflow or none, but sometimes spreading over thousands of square miles. Occasionally the lavas have been forced in between the beds of rock of a region so as to make great intercalated sheets, or have thickened up under the cover of other rocks into great dome-shaped masses, over a thousand feet thick, called by Prof. G. K. Gilbert "laccolites" (laccoliths).

A fissure in a case of ordinary non-volcanic igneous ejection affords its single outflow, and thus differs from a volcanic vent. Fissure may succeed fissure, however, and great thickness of beds be attained in the region through the successive discharges. But there could be no pericentric arrangement of the beds, or a higher central region, unless the fissuring be subordinate to a central vent; and in this latter case the ejections would be distinctively volcanic. But the characters of the flows and of the rocks are essentially the same, whether from fissures about a volcano or from those of non-volcanic regions.

IV. METHODS AND CAUSES OF VOLCANIC ACTION.

The Supplying of Lava. — A continued supply of lava from depths below is required for volcanic activity, since an enormous loss of lava takes place at an eruption.

Moreover, the supply-channel, or *conduit* as it is often called, must reach down to a region of perpetual heat and

fusion. For the liquid column loses heat, owing (1) to contact with the cool rocks alongside of it; (2) to the expansion of vapors or vaporizable material within the lava (all such expansion using up heat), which expansion becomes of large amount near the surface, as the superincumbent pressure in the liquid becomes small; and (3) to contact at surface with the air.

This supply of liquid rock from a deep-seated source supposes some upthrusting force or forces, sufficient to push the lava up to the level of the bottom of the crater. If the level reached is much below the earth's surface, say some thousands of feet, the melted rock might be a source of heat for any waters that may descend to it from the surface to bring it up, and might thus make hot springs or geysers, or at a higher level might produce a region of escaping vapors called a *solfatara*.

For volcanic action, the ascensive force, or combination of forces, must be sufficient to restore the lava-column to its mean height sooner or later after every eruption; for failure here is the beginning of decline in volcanic activity. When a volcano ceases action entirely, not even vapors escaping, it is said to be extinct; but it may not always be so dead that a century later it will not break out anew.

The Work inside the Crater at the Extremity of the Lava-column. — The work done in a crater is largely due to the expansive force of vapors, and directly to the making and escaping of vapors. For if all vaporizable material were absent, the lavas would lie quiet, and an eruption, if it were a possibility, would be simply a running over. Whenever, in the bottom of a crater or in any part of it, liquid lavas are visible, they are always found to be in constant activity; and if not actually in sight, there is usually considerable noisy action from the escaping steam, and from the movements below which it occasions.

The escape of vapor encounters resistance in consequence

of the cohesion of the liquid material, which resistance is proportional to the strength of this cohesion, or is conversely as the degree of liquidity. Water, in boiling, lets very small bubbles of steam through easily; and the elastic force of the steam of the bubble makes low jets, the height only one or two inches. But to overcome the resistance in lava and break a way through, the elastic force of a small bubble of vapor is too feeble; the bubble, therefore, keeps enlarging by additions until the force is sufficient to overbalance the resistance; and then comes the break of the liquid lava-shell of the bubble, and the projection of its fragments vertically or nearly so into the air, — vertically, because the shell is thinnest at top. The projectile force thus depends (1) largely on the size of the bubble, or, what is the same thing, on the viscidity of the liquid lava; and also on the supply of vapors seeking to escape.

On account of the remarkable liquidity of basaltic lavas, the projectile force required to break a way through may be so small as to throw the lava to a height of only a few yards, as in Kilauea, — a height so small that the projected drops or masses of lava fall back unsolidified, and the jets dance in a lively and brilliant way over the surface of the lava-basin, like those over a boiling vat. Where the surface of liquid lava is small, as in half-covered oven-like places about the sides of a basin, the escape of the vapors produces a throw of fiery spray.

Again: where such lavas are jetted out of small apertures, the driblets fall back upon one another, and, becoming soldered together, make fantastic driblet-cones. (Figures are given on pages 71, 85.) The projecting steam, in such cases, often escapes from the aperture with a rush like that from a steam-engine; hence the terms *blow-hole* and *blowing-cone*.

But when the liquid lavas are of the stiffer sort, the bubbles have to become large before escape of the vapor is possible;

and then, on breaking, the explosive force projects the fragments of the lava-shell to a height of hundreds or thousands of feet. The projected fragments, cooled in their flight, are the volcanic sand or dust, cinders or lapilli, which, in falling, make the cinder-cone about the vent, or cover slopes or the country about the volcanic mountain with thick deposits of loose volcanic ashes or scoria.

Such high projections have occurred under rare conditions in connection with the Hawaiian volcanoes. They are the common fact at most volcanoes; and it is well known that in some eruptions they reach a height of ten thousand feet and beyond. Great viscidity, while leading to the production of large size in the vapor-made bubbles before they are ready for explosion, makes fewer of them to form over a given surface of liquid lava; and in times of moderate activity the number may be only half a dozen or only a single one at a time, while on a like area lavas with the Kilauea degree of viscidity would have scores or hundreds. When the author was at Naples, in May of 1834, there was at night an interval of seven to eight minutes between the explosions, or the throw (some hundreds of feet in height) of fiery cinders; on the ascent, the following day, the interval was four to five minutes; and on passing Stromboli, a fortnight later, June 16, it was fifteen to twenty minutes, — the activity being less than usual, explosions every two or three minutes being common. As Spallanzani, Hofmann, and others have seen the rising bubble within Stromboli, the bursting, and, following this, the rush of vapor and the cinder projections, there is no reason to doubt that at Vesuvius, also, each throw of cinders has the same source. Mr. John Milne states that on his ascent of the Japan volcano, Oshima, in May, 1877, on approaching the top, successive explosions were heard every two seconds with occasional pauses, which explosions he found, on reaching the top, to be due to successive outbursts of steam, each projecting ashes and lava-fragments to a

height of nearly six thousand feet, that fell vertically unless wafted by the winds.[1]

When the rains descend in torrents at a great eruption, these materials make the flowing mud that buries fields and forests, and has made fossils of cities, of which Herculaneum and Pompeii are examples.

The vapor of water, as has been stated, is the chief part of the vapors expelled. Above the surface of liquid lava, from which it escapes, it is for some distance invisible, because the temperature of the liquid lava is near 2000° F. It becomes clouds by condensation at whatever height the required temperature is reached.

For the supply of water, the sea may be a source; and so also the rains, whence come not only the streams of the surface but also subterranean streams. The waters may descend deeply into the cavernous volcanic mountain. Approaching the hot rocks about the lava column, they would be thrown into steam, — a cubic foot of steam, if under the ordinary atmospheric pressure, to every cubic inch of water. So vast is the amount of vapor that would thus come from a small amount of water, that the vapor, unable to escape through the rocks, would be forced into the rising lavas of the conduit. Moreover, a molecular absorption of vapor of water against the pressure within has been shown by Daubrée to take place.

Another source of water-vapor recognized among writers on volcanoes is the deep subterranean region which supplies the lavas. Further, if the fusion has been produced by the melting, through earth-movements or otherwise, of pre-existing rocks, the moisture of these rocks (perhaps half per cent of their weight) would be a source of rising vapors.

Other effects of the vapors are these: (1) They enlarge, by their expansion, the bulk of the liquid lava, and may thus

[1] Milne, "Volcanoes of Japan," Transactions of the Seismological Society of Japan, 1886, vol. ix. part ii.

increase the height of the lava-column. (2) They make vesicles or air-cells in the lava. (3) They produce fractures in the walls of craters or in the sides of the volcanic mountain by the sudden generation or slower accumulation of large quantities within regions about or beneath the crater. (4) They may produce violent projectile effects when water in large quantity gains direct access to the lava-conduit. (5) They bring pressure to bear on surfaces of liquid lava beneath, and often force the lava into opened fissures and up to levels hundreds of feet above the bottom of the crater, acting here on the principle exemplified in a Pennsylvania oil-well.

Progress toward an Eruption. — The crater, after it has been emptied by a great discharge at a time of eruption, often has, at first, a period of apparently extinguished fires, and something like the conditions of a commencing solfatara, through the lazy escape of vapors from the fissures and the lining of fissures with sulphur crystals. Next, little outflows of lava take place from apertures or fissures in some part of the bottom or floor of the crater, or driblets of lava or jets of cinders build a small cone about a vent. In the case of basaltic lavas, pools of boiling lava often appear in the crater, which frequently overflow and spread lava-streams over the floor, making thus small eruptions. In the case of the less liquid lavas the ejections at the bottom of the crater are mostly of cinders, and one or more cinder-cones are made thereby over the bottom; but now and then escapes of lava take place through fissures. The process is one that puts new material over the bottom of the crater and raises its level; and it goes on at an increasing rate until the eruption commences.

But this raising of the bottom by overflows and deposits of cinders is accompanied by the upward thrust of the lavas of the lava-column through the ascensive action already mentioned. Owing to this ascensive action, aided by the ejec-

tions, the floor of the crater keeps rising; and sometimes, perhaps generally, the larger part of the floor is lifted or shoved up bodily by the lavas forced in beneath.

By these methods the level of the floor in a volcano like Vesuvius may rise nearly to the very brink of the crater; or, in one like Kilauea, at least some hundreds of feet. At such times the projectile action of the crater has become intense. Clouds rising in great volumes over the mountain are evidence of the activity, and an illuminated signal at night.

The Eruption. — The eruption begins when the pressure from the vapors generated and confined below and from the hydrostatic pressure of the lava-column — chiefly the former — is too great to be withstood by the containing mountain. The mountain therefore breaks, the conduit is rent open on one side or the other, and the lavas run out. If the mountain is too strong to break, as it perhaps is in the earlier part of its history when it is of little height, the lava would rise to the top of the crater by the methods stated, and overflow on this side or that; and thus the lava-flood would begin at the summit. But eruptions at the present day, as has been stated, are usually through fissures.

The discharge of the lavas (1) empties the upper part of the lava-conduit or lowers the level of its upper surface, and (2) undermines the lifted crater-floor; and the result may be (3) a collapse or down-plunge within the crater, making it again hundreds of feet deep, or a thousand, or two thousand, as the case may be.

Part of the undermining at Vesuvius is due to outflow of lavas, part to discharge of volcanic cinders; but at Kilauea it all comes, ordinarily, from the escape of liquid lavas.

The collapse from the loss of lavas may be followed by a general chilling of the rocks down to the new lava-surface, and a long period of quiet. Before the mountain is ready

for another eruption the process of filling up again, by the methods described, has to be repeated, and this may take many years. An empty caldron will not overflow before its cracks are mended and the steam-apparatus at work has again filled it; and it might be so badly cracked, and the supply of heat so cut off, as to fail of further use. Should the ascensive force for any cause cease to work, death would be sure.

Earthquakes in connection with Volcanic Eruptions. — When the breaking of the mountain is caused by vapors suddenly produced in large volume, and the resistance to fracture is very great for any reason, the vibrations attending the rending may be vigorous, opening deep fissures, overturning houses, and making underground rumblings. But in other cases the vibrations may be imperceptible, as is usually the fact both in Kilauea and Mount Loa at their greatest eruptions.

Subordinate or Lateral Volcanic Cones. — Lateral volcanic cones are described, on page 3, as sometimes forming over fissures. Each such cone when it is in progress has its own lava-column, as a branch from the general lava-column of the mountain. But it is relatively small, and the liquid lavas consequently may soon become chilled by the cold rocks about it; and hence such lateral or subordinate volcanoes have usually only a brief existence. They, however, often work hard while the time lasts, and even in two or three weeks may make a cone many hundred feet or yards in height. They occur about the sources of great eruptions. But they are most common near the seashore, where subterranean fresh waters most abound for the supply of moisture, and where the sea is at hand as another source. The volcanic origin of such cinder-cones can be proved, if a fact, by the *pericentric* arrangement of the materials constituting them. The sea, with its broad waves and the aiding winds, can make heaps or ridges out of the sands existing or pro-

duced on its borders, but it cannot arrange the layers of sand or earth pericentrically into a conical hill.

Explosive Eruptions. — When water in large volumes gains sudden access to the *interior* of a lava-conduit, — that is, to the liquid lavas of the lava-column, — the projectile force of the abruptly generated vapors may be enormous, and produce projectile discharges of lava of terrific violence, covering a wide reach of country with volcanic cinders and ashes. Moreover, great masses of solid lava may be torn off in such cases from the throat of the volcano, and add to the projections. Masses of a hundred cubic feet and more may be hurled for miles from the scene of explosion. Such an eruption is very unlike the ordinary kind described above. It is an *explosive* eruption. In some of the most violent of explosive eruptions no outflow of lava takes place. The projectile eruption is all, and this is soon ended. Some examples of such eruptions are described on a following page.

Explosive eruptions of another kind, which might be styled *semi-volcanic*, are included among described volcanic phenomena. In such eruptions water in large volumes gains sudden access to the heated depths beneath an extinct or feebly active volcanic mountain through fractures or movements along planes of weakness, as in other cases; but the heated depths are depths short of the 2000° F. or over required for fusion. The consequences are earth-shakings, explosions from the suddenly generated steam, the rending of rocks in the deep-seated region of the explosions, projectile action throwing the stones and great rock-masses so made and the dust from abrasion into the air and over the adjoining region, attended by vast and violent effusions of steam, making darkness and terrific storms about the mountain, — and not outflows of lava nor the projection of volcanic ashes and scoria from cooled lavas. No liquid lavas are in any way directly concerned, and hence the eruptions are only semi-volcanic. They may get over their violence in an hour or less.

Such projections make great cavities beneath, undermining the mountain; and a down-plunge or subsidence of the mountain summit to fill the cavities should be a consequence. Since force acts most violently where the generator of the steam exists, as in other explosive eruptions, and comparatively feebly after the vapors have made their escape into the open air, the chief destruction to the mountain cannot come from any blowing of steam, or air, or projection of rocks, against the outside walls or peaks.

The *origin of volcanic heat*, the *source of lava-columns* beneath the volcano, the *cause of the ascensive force* in the lava-column are subjects on which science has various opinions and no positive knowledge.

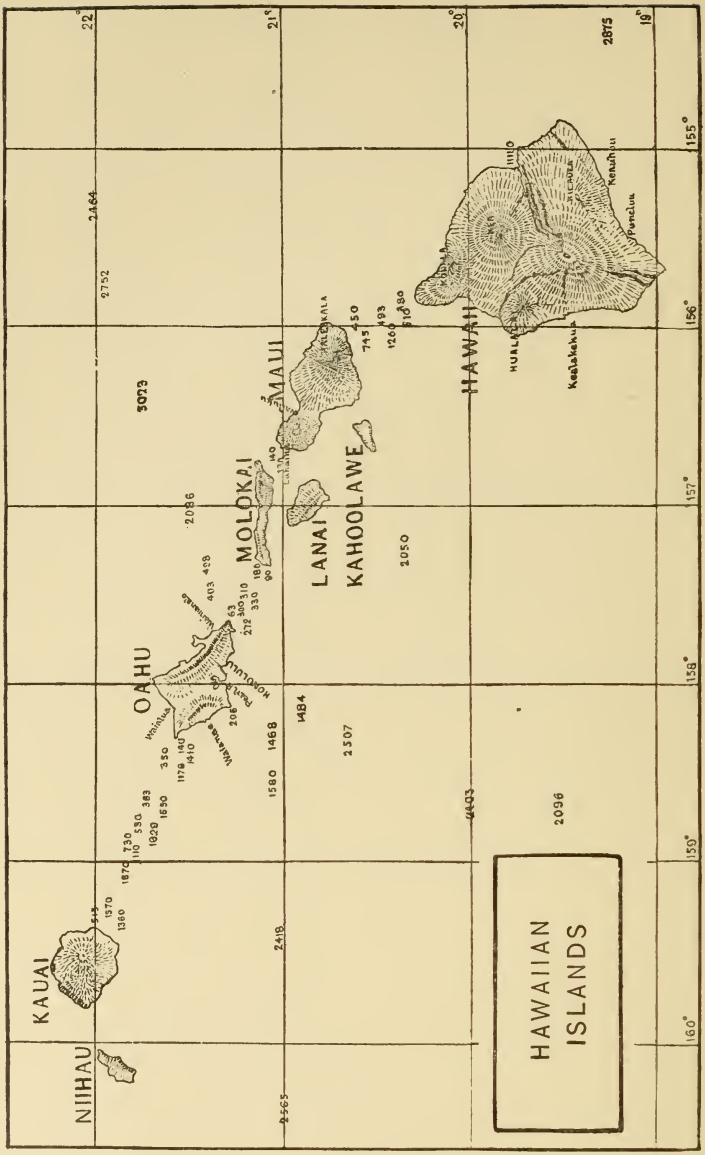
Part Second.

CONTRIBUTIONS FROM THE HAWAIIAN ISLANDS TO THE SCIENCE OF VOLCANOES.

THE Hawaiian Island group is an example of a line of great volcanic mountains. Fifteen volcanoes of the first class have existed, and have been in brilliant action along the line. All but three are now extinct; and these three are on the easternmost and largest island of the group, — Hawaii. Hawaii is made up of five of the volcanic mountains, — Kea, 13,805 feet in height; Loa, 13,675 feet; Hualalai, 8,273 feet; Kilauea, 4,040 feet at the Volcano House, but 4,158 feet at the highest point on the west side; and Kohala, 5,505 feet. But they have encroached much on one another by their eruptions; and Kohala, the oldest and most northern, is largely buried by the lava of Kea.

The island of Maui is a volcanic doublet. The eastern mountain of Maui — Haleakala, 10,032 feet high — looks as fresh in its lavas and as smooth in its slopes as a volcano still in activity. But the other mountain — that of western Maui or Eeka — has lost by long denudation its summit crater, its old even slopes, and a large part of the old cone.

Oahu is another volcanic doublet; and both its eastern and western mountains have, like Mount Eeka, lost the crater that was the great centre of action; and besides they have lost much also by catastrophes of a subterranean source.



Still the lava-streams of the old cones may be made out on each, and in one perhaps the site of the ancient crater.

Molokai is another volcanic doublet; and probably also Kauai, although the larger part of the present island appears to belong to one great cone or dome.

The group appears, in fact, to be a double line of volcanoes from Oahu eastward. One line, the northern, called the "Kea Range" from Mount Kea of Hawaii, includes the northeastern mountain of Oahu, Molokai, the two mountains of Maui, and Kohala and Kea on Hawaii; the other, the "Loa Range," includes the southwestern mountain of Oahu, Lanai, Kahoolawe, and the volcanoes of Hualalai and Loa on Hawaii.

The island Niihau, at the west end of the group, southwest of Kauai, has a position transverse to that of the general trend of the islands.

The depth of ocean about the islands, so far as soundings have been made, varies from 2,000 to 3,023 fathoms, as is shown on the map; and as the cones stand on the sea-bottom, the whole height of the higher mountains of Hawaii above the base to the eastward is not far from 31,000 feet.

The Hawaiian group is an example of the lines of volcanoes that characterize many island ranges over the globe and volcanic ranges over the continents.

The volcanic features and phenomena of the Hawaiian Islands are described and discussed in the following pages from personal observations in 1840 and 1887, from the various records of others, and from the topographic surveys of the islands made under the direction of Prof. W. D. Alexander, Surveyor-General of the Hawaiian Islands.

As the island of Hawaii is the field of existing volcanic fires, and therefore of greatest interest, the facts relating to it and the views on volcanic action thence deduced come first under consideration, after general remarks on the group, and then the results of observations on the other islands, and the relations of the group to the system of islands in the Pacific Ocean.

I. THE ISLAND OF HAWAII.

General Observations. — A map of Hawaii makes the frontispiece to the volume. The island is approximately triangular, with its greatest length from north to south about ninety-three miles, and the extreme width eighty miles. It lies mostly between the parallels of 19° and 20° 20′, and takes the trades on its northeast side.

Many important facts may be read from the map at a glance. Among them the first to be noted is the simplicity of the topography and the gentleness of the mountain slopes; secondly, the situation of the five volcanic mountains; thirdly, the almost total absence of rivers, except on the north and northeast slopes, or the windward sides; and fourthly, the courses of the great lava-streams of the past sixty years, indicated by long dotted areas.

The Kohala Range, on the north, is the remains of the oldest of the Hawaiian volcanoes. The slopes are deeply cut by valleys of denudation. Between it and Mount Kea lie the broad plains of Waimea, 2,500 to 3,000 feet above tide-level, made by the lavas of the base of Mount Kea. On the northeastward, the ocean side, there are the precipitous gorges of Waipio and Waimanu, 1,000 to 2,500 feet in depth, so profound and so bent around into parallelism with the coast that erosion cannot explain their origin.

Mount Kea has long been extinct, probably for centuries, yet not long enough for denuding action from the abundant rains over the windward slopes to extend the torrent channels more than half-way to the summit. Mount Hualalai has been quiet since 1801, when the last eruption was witnessed by Turnbull. It is a question whether it did not reach final extinction as a consequence of that discharge. Its slopes so blend with those of Mount Loa that "it is hard to tell where one begins and the other ends." Mount Loa

blends in like manner with Mount Kea, but with a broader intervening plateau, about five thousand feet in elevation. The great Dome of Mount Loa[1] would have been the highest of the mountains, were it not for the last cinder-eruptions of Mount Kea, which ran up a cinder-cone to a height of one hundred and forty feet above it.

Kilauea is twenty miles south of west from the crater of Mount Loa; and although containing the largest crater of the group, the highest point is raised hardly three hundred feet above the plain between it and Mount Loa, and within two miles in that direction the Kilauea slope ends. In the opposite direction Kilauea may claim the slopes to the shores, from Haena, southeast of Hilo, to the middle of the south coast within ten miles of Punaluu.

Hawaii has no fringing reefs; only small patches occur here and there along the shores. The fact is a consequence of the destruction of life from submarine eruptions, and the encroachment also of subaerial lava-floods. It has therefore no first-rate harbor. That of Hilo is the best; and the village of Hilo is consequently the chief settlement. The longest of Hawaiian rivers, the Wailuku, which follows in its lower part the meeting of the slopes of Kea and Loa, here enters the sea, and adds much to the capabilities and the beauties of the surrounding region. At the Pei-pei Falls above Hilo, it flows between high bluffs of basaltic columns.

Hilo is the usual starting-point for excursions to Kilauea. The old saddle-road is indicated on the map by a dotted line. The distance is about thirty miles. 17½ miles of it beyond the "Half-way House." The new carriage-road, which follows nearly the same course, has reduced the time of the journey, and added much to its pleasures. Another and a much shorter route is from Keauhou, on the southern coast. It makes the whole ascent of 4,000 feet in about ten miles' direct distance, or twelve miles by the road, rising 852 feet in

[1] The words "Mauna Loa" mean "Long Mountain."

the first mile, and between the third and fifth miles (as the road goes) about 700 feet, which carries the road to the summit of the "pali," or a long precipice that here extends along for more than twenty miles parallel nearly with the coast.[1] A third route to Kilauea, and one of much interest, starts from Punaluu, on the southern coast, where there is a good hotel. The steamer to and from Punaluu passes around the southern cape, and affords a chance for a distant view of the lava-streams of 1868 and 1887, at the commencement of whose discharge earthquakes shook the whole island, and the southern half of it disastrously.

Kealakekua, on the west coast, is the place where Captain Cook was killed by the natives in 1779. It is an interesting place geologically on account of the lofty cliffs that here face the sea, — evidence apparently of great fracturing and subsidence.

The slopes of Mount Loa are under forests up to from seven to eight thousand feet on the north and east sides, and over much of the southeast to a line drawn from the summit through Kilauea, — the limit of the region struck by the trade-winds. The rest of the surface, with part also of the forest portion, is a nearly bare surface of lava-streams, either the pahoehoe or *aa*, with little shrubbery. The fields of *aa* are the chief obstacle in an ascent to the summit outside of the usual track. As the jagged masses are from one cubic foot to ten thousand in size, and touch only by their points and edges, leaving deep recesses everywhere among them, any crossing on horseback, except by a made road, is impossible; and the pedestrian has to

[1] The road was made by the Wilder Steamship Company, and they publish the following as the levels of the road at each mile-stone along it, starting from Keauhou: 1st, 852 feet; 2d, 1,113; 3d, 1,841; 4th, 2,287; 5th, 2,504; 6th, 2,867; 7th, 3,204; 8th, 3,341; 9th, 3,395; 10th, 3,629; 11th, 3,748; 12th, 4,008; 13th, 3,964; 14th, 4,040, Volcano House. The Keauhou Ranch, a half-way house, is six miles from Keauhou Landing; at nine miles the road sends off a branch to the southeastward to Puna. The Volcano House is under the direction of the Steamship Company.

look to it that he does not miss his footing and break his limbs in a fall among the jagged masses. Moreover, some *aa* fields are so large that when upon them all in sight to the horizon around is gray and black desolation. The author made his first acquaintance with the two styles of lava-fields in 1840 on his walk from Kaulanamauna, on the southwest coast, to Waiohinu, Honuapo, Punaluu, and Kilauea.

The pahoehoe also is exceedingly uneven, through its many rounded hillocks or domes (half of which are caved in), its ropy ridges, and its knobs and mouldings made by the extrusion of flowing lavas through the hardened crust of a stream; but travelling over it is safe, and a mule will avoid the holes and crevices.

The General Character of the Great Craters and of the Facts they afford. — The active craters of the island — Kilauea, and Mokuaweoweo or the Mount Loa crater — are alike in being *pit-craters*, or craters with mostly vertical walls without an enclosing cone above the walls; and these walls are made of the nearly horizontal edges of stratified lava-streams.

A sketch of Kilauea, as it appeared in December, 1840, by Drayton, one of the two artists of the Wilkes Exploring Expedition, is reproduced in Plate II. from the "Narrative of Captain Wilkes."[1] A knowledge of the features of the pit at that time is necessary to enable the reader to understand the history beyond. It was taken from the west angle of

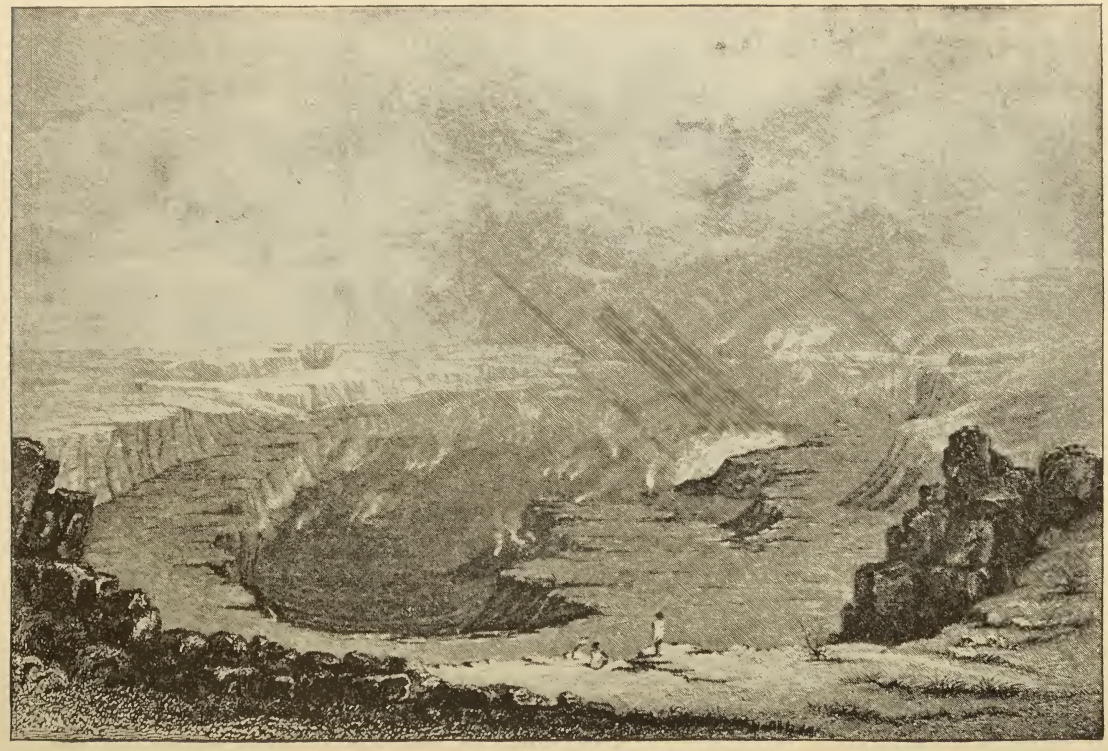
[1] Copied from the plate facing page 125 in the fourth volume of Wilkes's "Narrative." One or two points of geological importance were overlooked by the artist, which should be mentioned to forestall wrong inferences: One is the omission of the stratification of the wall, which is a marked feature; and another is the giving a slight concavity to the floor of the crater in the northern or near part, which was not a fact. The small jets of vapor over the bottom arose at the time, with a single exception, from fissures or cavern-like openings; and such escapes of vapor are greatly multiplied by a rain. The exception was that of a lava-lake, about two hundred feet in diameter, named Judd's Lake in the "Narrative," which was the larger of two lakes that were active two months before, in November, 1840, at the time of the author's visit to the crater.

the depression at the north end of the crater, and shows admirably the condition of the pit. Its length then was fourteen thousand feet, as now; but its depth to the bottom of the lower pit was one thousand feet. The broad, level platform between the lower pit and the upper wall, about six hundred feet below the top of the wall, is what was then called the "Black Ledge." At the present time, as shown on Plate III., there is no lower pit and no Black Ledge; all is filled up to a higher level than that of the ledge, so that the greatest depth below the Volcano House is now but 482 feet, and the least about the centre of the pit is less than four hundred feet.

The most active fires in 1840 were in the southwest part of the crater, as has been the fact through all the known history of Kilauea. The pit represented in the sketch to the left is the small crater of Keanakakoi, which is well shown in Plate III.

The history of these volcanoes is such as has been supplied by no other volcanic region. Commonly it is the eruption that draws attention to the volcano; and the course of the flow, the characteristics of the lava, and the devastations of the fiery stream and the earthquakes make up nine tenths of all the published facts. At Kilauea, on the contrary, it is a history of the *inner workings* of the volcano; of the movements and changes that take place within the crater over the various parts of the great area, where come into view the outlets of the subterranean lava-column; and of these events as steps in the line of progress from its emptied condition after a great eruption till ready again for an outbreak.

In Vesuvius the crater may be accessible for a time after a discharge; and Scacchi has done excellent work on such occasions. But in general, long before the time of eruption, the vapors and cinder ejections make access to the bottom impossible. The crater of Ætna is far away from habita-



CRATER OF KILAUEA. J. Drayton, U. S. Expl. Exped., 1840.

tions, and it has therefore had no regular series of interior investigations. Kilauea alone is always accessible. Although the crater is so large, the height is no greater than that of Vesuvius. Even when ready for an eruption it is safe to stand on the brink of the great pit and watch the boiling caldrons, and sweeping lava-floods, and violent but harmless blowing-cones. The action of the liquid lavas is ordinarily so quiet and regular that all parts of the great open arena may be traversed with safety; and the margins of the fiery lakes, if the heat is not too great, may be made a sleeping-place for the night, — with only this possibility, that the lavas may well up and spill over. This spilling over may be the sending away of a stream for a mile or two across the crater's bottom; but standing a little to one side it does no damage, and the next day the fresh lavas may be walked upon. Thus the crater may be followed in all its interior changes month after month. There is terrible sublimity in the quiet work of the mighty forces, and also something alluring in the free ticket offered to all comers.

The records of such a region, whoever the reporter, are of great importance to science; and where descriptions are seemingly overdrawn it is easy after a little experience to select the facts.

Publications relating to the Hawaiian Volcanoes. — The earliest records of Hawaiian lavas and of the crater of Kilauea are contained in the "Journal of a Tour around Hawaii [in August, 1823] by a Deputation from the Mission of the Sandwich Islands," 264 pp. 8vo, with six plates, which was published at Boston, in 1825, by Crocker & Brewster. The statement is made that it was "drawn up by the Rev. William Ellis," of England, one of the party, "from minutes kept by himself and by his associates on the tour, who subsequently gave it their approbation." It contains, facing page 136, a night view of "the south end of Kilauea," from

a sketch taken by Mr. Ellis, looking southwestward, engraved by Mr. S. S. JOCELYN, an artist of New Haven, Conn. The position from which the sketch was taken is indicated in the following words. "Leaving the north end of the crater," says the "Journal" (p. 145), "we passed along to the east side, where Mr. Ellis took a sketch of the southwest end of the crater." In the next sentence it is added: "As we travelled from this spot we unexpectedly came to another crater," nearly half as large as the former. The native name of it is Kirauea-iti (Kilauea-Iki, as now written); "it is separated from the large crater by an isthmus nearly one hundred yards wide." The position from which the view was taken was hence north of Byron's hut (p. 51), either on the isthmus referred to or farther north on the bluff adjacent. A notice of the "Journal," with citations, is contained in the "Missionary Herald," 1828, xxii. 28.

In 1826 a London edition of the work, "with large additions," was issued by Mr. Ellis, under the title "Narrative of a Tour through Hawaii;" and a third edition, of 480 pages, was issued in March, 1827. The "Narrative" contains, facing page 226, a day view of the "southwest end" of Kilauea, engraved in England from the same sketch that was used by the American engraver; for the remark about the spot from which it was taken is repeated on page 247. The view, for some unexplained reason, is made to differ widely from the earlier; for a large cone stands where was the foot of a lava-stream descending the west wall, and, besides this, two of the cones in the bottom of the crater are omitted, and the active cones in the crater emit vapors quietly. These two views are presented, half size, on pages 46, 47.

Mr. Ellis reproduced his descriptions and his view of the crater in the second edition of his "Polynesian Researches," which was published in four volumes duodecimo in London in 1831. The earlier edition of the "Researches," of two volumes only, contained nothing about Hawaii. In prepar-

ing the work for the second edition, the "Narrative" was added as the fourth volume; and, for a frontispiece to this volume, a new engraving of Kilauea (from a painting, a night view) was introduced, having the subscript. "The Volcano of Kilauea in Hawaii. Sketched by W. Ellis. Painted by E. Howard, Jr. . . . London, 1831." An outline copy of this view is introduced beyond, on page 50. It differs widely from those of 1825 and 1826; and since the statement of the "Narrative" as to where the sketch was taken is again repeated, the source of the differences has no explanation in the work. The cones are fewer, but they are as active; and one, placed out in the front, is a grand high-shooter, far outdoing any of those on the other plates. Further, the features of the black ledge and the wall above are changed on both sides of the pit, and the Great South Lake is put in a *southeast* recess instead of to the southwest. Mr. Ellis was a second time at Kilauea, but this was before 1826. He then found the crater much more quiet, and "the fires in the south and west burning but feebly."

The next publication containing details on the Hawaiian volcanoes is the Rev. C. S. Stewart's "Journal of a Voyage to the Pacific Ocean and Residence at the Sandwich Islands during the Years 1822–1825," published in New York in 1828. It contains an account of a visit to Kilauea, which was made on the 2d of July, 1825. A citation from the account is contained in the "American Journal of Science," 1826, xi. 363. Mr. Stewart was again at the Islands in 1829, and in 1831 published in New York his "Visit to the South Seas," in two volumes, duodecimo. It is noticed in the "American Journal of Science," 1831, xx. 229.

In the years 1824, 1825, H. M. S. "Blonde," under the Right Hon. Lord Byron, as commander, visited the islands; and at London, in 1826, appeared his "Voyage of the 'Blonde' to the Sandwich Islands," in a quarto of 260 pages, with several plates. The visit to Kilauea was made on

June 28, 29 (29, 30, American time). It is illustrated by a folded plate presenting a view of the volcano, by R. DAMPIER, in which the many cones give out vapors quietly, and also a map of the crater by Lieutenant MALDEN, R. N. (See p. 51.)

Between 1825 and 1841 appeared in the "American Journal of Science," the "Missionary Herald," and elsewhere, letters or papers by Rev. JOSEPH GOODRICH, dated 1825, 1828, 1832; by Rev. A. BISHOP, letter of 1826; by Rev. L. CHAMBERLAIN, 1824; by Messrs. CHASE and PARKER, prepared by E. G. KELLEY, 1838; by Capt. JOHN SHEPHERD, R. N., 1839; and by Rev. TITUS COAN, 1840.

Besides these, there appeared in 1836, in the "Companion of the Botanical Magazine," ii. 79–182, a memoir of DAVID DOUGLAS, by Dr. W. J. Hooker, with a portrait, letters, and journal. Mr. Douglas spent a dozen years in travels over North America, visiting Oregon, California, Hudson's Bay region, etc., as an exploring naturalist, and twice visited the Sandwich Islands, making collections and observations in botany, zoölogy, etc., part of the time under the auspices of the Horticultural Society of London. His instruments included a barometer, chronometers, a reflecting-circle, large dipping-needle, etc. He made his visit to Kilauea on Jan. 23–25, 1834, and that to the top of Mount Loa on the 29th of the same month. The account of the latter journey is contained in his journal on page 175 of the above-mentioned memoir, and in a letter to Dr. Hooker on page 158. Besides, there is an important letter from him to Captain Sabine, dated Oahu, May 3, 1834, taken partly from his journal, but containing additional material on his barometric, hygrometric, thermometric, and hypsometric observations, published in the "Journal of the Royal Geographical Society," 1834, iv. 333–334. Extracts from the journal of Mr. Douglas are contained in the "Magazine of Zoölogy and Botany," 1837, i. 582, which includes the letter to Dr. Hooker describing Mount Loa. While on an excursion

over Hawaii in July, 1834, Mr. Douglas, then thirty-five years old, fell into a pit made to entrap wild cattle and was gored to death.

In the year 1838 Count STRZELECKI visited Kilauea; and in his "New South Wales and Van Diemen's Land," published in London in 1845, he has an account of his observations cited, in quotation marks, from his "manuscript notes." The "Hawaiian Spectator," i. 436, contains a note from him on the subject, with a different statement of the facts. (See p. 61.)

The author's first observations on the Hawaiian Islands were made in the months of October and November of 1840, and during ten days in November of 1841, while connected with the Wilkes Exploring Expedition around the world, and they are reported upon in his "Expedition Geological Report," published by the Government in 1849.[1] They occupy pages 155–284 and 353–456, where they are illustrated by a colored geological map of Oahu and many figures in the text. The islands studied were Oahu, Kauai, and Hawaii,—the last as far as could be done in the commander's allotted week. A second visit was made in August and part of September, 1887, when further observations were made on Hawaii and Oahu, and the volcanic mountains of Maui were for the first time visited.[2]

Capt. Charles Wilkes also has a report on the Hawaiian volcanoes in Volume IV. of his "Narrative of the Exploring Expedition," published in 1845, in five volumes, royal octavo. The account given is partly his own and partly that of his officers, including the excellent and faithful artist of the expedition, Mr. J. Drayton.

[1] Geology, 756 pages, 4to, with a folio atlas of twenty-one lithographic plates.

[2] The facts observed in this second visit are reported upon in the "American Journal of Science," in a "Memoir on the Volcanoes and Volcanic Phenomena of the Hawaiian Islands," published in vols. xxxiii–xxxvii. This memoir is closed by a paper by Prof. E. S. Dana on the petrology of the islands; and its contents are reproduced in this volume.

After 1849, Rev. Titus Coan became the chronicler of the Hawaiian volcanoes; and very much is due him for his laborious excursions, and his many accounts of the volcanic changes in progress and of the great eruptions of Kilauea and Mount Loa. The larger part of his communications on the subject appeared in the volumes of the "American Journal," the last in the year 1882. He also published notes on some of the eruptions in his "Life on Hawaii," 1882. Accounts from other observers and also many of Mr. Coan's appeared also in the daily newspapers of Honolulu. Among the most important was a paper by Prof. C. S. Lyman, in the "American Journal of Science" for 1851 (vol. xii.), giving an account of his observations in 1846. Others are mentioned beyond, with references.

During the years 1864, 1865, Mr. William T. Brigham made a study of Kilauea and Mount Loa; and he published the results of his work, with maps and other illustrations, in a memoir of 126 pages, quarto, published in 1868 in the "Memoirs of the Boston Society of Natural History." His memoir contains also a map of the crater of Kilauea, from a new survey by himself, a history of the Hawaiian eruptions, and a general review of Hawaiian geology. He has a second paper in the "Memoirs of the Boston Society," i. 564, with a map on page 572, based on his own observation and the descriptions of the eruption of 1868. Mr. Brigham was again at the islands in 1880, and brief notes by him on the visit are published in the "American Journal of Science" for 1887.

In 1882 Capt. C. E. Dutton studied portions of the islands, including especially Hawaii and Maui. His account of his observations, with plates and maps in illustration, together with discussions on points in the science of volcanoes, covers 140 pages in the "Fourth Annual Report of the Director of the United States Geological Survey, 1882–1883."

In 1885 Rev. J. M. Alexander surveyed and mapped the

Mount Loa crater; his paper on the subject is contained in the "American Journal of Science," 1888, vol. xxxvi.

In 1887, after the eruption of Kilauea in March of 1886, appeared important papers on the condition of the crater later in the year 1886 by Mr. J. S. Emerson and Mr. Frank S. Dodge, assistants in the Government Topographical Survey, and by Prof. L. L. Van Slyke, of Oahu College, in the "American Journal of Science," 1877, xxxiii. 87.

Another work of much value appeared at Honolulu in 1887: Part II. of "The Vestiges of the Molten Globe; or on the Earth's Surface Features and Volcanic Phenomena." By William Lowthian Green. A volume of 337 pages, with a map.

Besides the above works and papers there are traditions of a violent eruption of Kilauea in 1789, which were collected and published in 1843 by the Rev. I. Dibble, as stated beyond.

A. KILAUEA.

1. Kilauea before 1823.

Eruption about the Year 1789. — The account of the eruption of 1789, or about that time, was gathered from the natives by the Rev. I. Dibble and published in his "History of the Sandwich Islands," at Lahainaluna (Island of Maui), in 1843. It was taken by the author from the lips of those who were part of the company and present in the scene, and is as follows: The army of Keoua, a Hawaiian chief, being pursued by Kamehameha, were at the time near Kilauea. For two preceding nights there had been eruptions, with ejections of stones and cinders. "The army of Keoua set out on their way in three different companies. The company in advance had not proceeded far before the ground began to shake and rock beneath their feet, and it became quite im-

possible to stand. Soon a dense cloud of darkness was seen to rise out of the crater, and, almost at the same instant, the thunder began to roar in the heavens and the lightning to flash. It continued to ascend and spread around until the whole region was enveloped, and the light of day was entirely excluded. The darkness was the more terrific, being made visible by an awful glare from streams of red and blue light, variously combined through the action of the fires of the pit and the flashes of lightning above. Soon followed an immense volume of sand and cinders, which were thrown to a great height, and came down in a destructive shower for many miles around. A few of the forward company were burned to death by the sand, and all of them experienced a suffocating sensation. The rear company, which was nearest the volcano at the time, suffered little injury; and after the earthquake and shower of sand had passed over, hastened on to greet their comrades ahead on their escape from so imminent peril. But what was their surprise and consternation to find the centre company a collection of corpses! Some were lying down, and others were sitting upright, clasping with dying grasp their wives and children, and joining noses (the mode of expressing affection) as in the act of taking leave. So much like life they looked that at first they supposed them merely at rest, and it was not until they had come up to them and handled them that they could detect their mistake." Mr. Dibble adds: "A blast of sulphurous gas, a shower of heated embers, or a volume of heated steam would sufficiently account for this sudden death. Some of the narrators, who saw the corpses, affirm that though in no place deeply burnt, yet they were thoroughly scorched."

The "sand and cinders" of this eruption (the latter usually called on the island *pumice*[1] on account of its extreme lightness, and first mentioned by Ellis, who says "light as a

[1] Pumice is the scoria of a trachytic or some orthoclase-bearing lava, with the vesicles linear.

sponge"), are well known to cover an area of "many miles" to the southwest of the crater; but the accounts of the region have said nothing about the stones until the publication of Prof. C. H. Hitchcock in "Science" of February, 1887, after his visit to the crater in the summer of 1886. He there reports that, "standing at Keanakakoi, one sees to the southwest and south a stretch of volcanic sand and debris fully equal in dimensions to Kilauea itself. On examining more closely the material called 'gravel' on the map, it was seen to consist of material ejected from the volcano, and numerous lava-bombs were picked up. Ashes also cover the country to the south and southwest over the Kau desert for several miles."

The author was over the region here referred to in 1887. In accordance with Mr. Dibble's words "many miles around," the deposits exist through the whole circuit of Kilauea, even the vicinity of the Volcano House; and the projection of stones preceded that of the light scoria ("pumice"), yet it was itself preceded by a great shower of volcanic ashes or sand. The stones are in great numbers and of large size to the west and northwest of the crater. The deposit has its maximum thickness over a large area south and southwest of the crater, where it is twenty-five to thirty feet thick and extends ten miles or more away. It is well exposed to view along the fissures. The lower twenty to twenty-five feet of the deposit consist of yellowish-brown beds of tufa, the material very fine volcanic sand and hardly consolidated. Above the tufa are two to three feet of a coarse conglomerate consisting chiefly of stones; and above this stratum, a bed twelve to sixteen inches thick of closely packed brownish sponge-like scoria ("pumice"), in pieces half an inch across to two or three inches.

This sponge-like scoria contains the least possible amount of solid matter, being about ninety-eight and one-third per cent air, the rest glass; for the small round cells have

no walls except a few slender threads, and it is as light as a dry sponge. (See p. 163.) On account of its lightness it is easily carried off by the winds as well as by the sleepiest of waters, and hence the bed is often left in patches.

The ejected stones vary in size up to several cubic feet. Those of one to two cubic feet are common, many are twenty to thirty, and one seen by the author on the west side of Kilauea measured one hundred cubic feet and must have weighed over eight tons. Part are ordinary volcanic scoria; but the most of them consist of the more solid basalt sparingly vesicular; and many of the larger are of a light gray kind very slightly vesicular or hardly at all so, very sparingly chrysolitic, and frequently having on the worn exterior a faint banded appearance from alternating variations in compactness of texture. Another kind varies in color from faintly reddish to gray, is more or less vesicular, and contains a large amount of chrysolite.

Going from the southwest border northward and approaching the highest point on the west side, the Uwekahuna station of the survey, the deposit becomes thinner, but retains well its characteristics. North of this station the thickness becomes ten feet and less. At the Volcano House it is six feet or more. It may be seen in front of the house at the first descent, where it includes, at bottom, a bed of pebbles; upon this, six to eight inches of the spongy scoria ("pumice"); then another pebbly layer and some fine tufa. It occurs also just north of the Volcano House garden, and may be found in traces elsewhere about the north border.

From the south border of the crater the formation extends around by the east side not only to Keanakakoi, but to the Kilauea-iki depression, thinning northward as on the west side, but having the same characteristics, as observed in the spongy scoria, the great numbers of large stones and the kinds of rock constituting them. But the stones, though

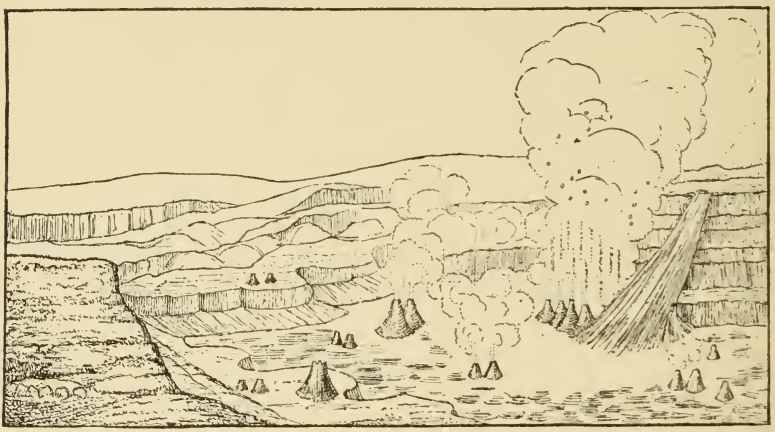
many and large, are of somewhat less size than to the west and southwest, and the "pumice" to the northward on this windward side of the crater is in thin widely scattered patches. The tongue of land extending from that side toward the south end of Halema'uma'u, with the words "gravel and bowlders" over it on the map, owes its gravel and many bowlders to the same source, as Professor Hitchcock implies. The low plain between Kilauea-iki and Kilauea fails of it; but this is owing to recent lava-outflows over the surface. The deep soil and earth farther east, over a region crossed by the north and south carriage-road on the route from Keauhou to the crater, bearing tree-ferns in luxuriance, is probably an eastern portion of the tufa formation.

The greatness and violence of the eruption cannot be doubted. The distribution of the ejected stones, ashes, and scoria all around Kilauea seems to show that the whole bottom of the pit was in action; yet the southern, as usual, most intensely so. The heavy compact rock of the stones and the size of many of them indicate that the more deep-seated rocks along the conduit of the volcano were torn off by the violent projectile action. It was an *explosive* eruption of Kilauea such as has not been known in more recent times.

2. Kilauea from 1823 to 1841.

The recorded history of the crater of Kilauea — "Lua Pele" of the islanders — commences with August, 1823, the time of the visit by the deputation of missionaries mentioned on page 35. A great eruption had taken place in the preceding spring between the months of March and June; so that the condition was that of the crater emptied and just starting anew in the preparation for the next eruption. The fact as to an eruption but a short time before was inferred by the deputation from the existence of a "black ledge," as

it was then called, running like a terrace-plain around the interior some hundreds of feet above the bottom; "for it was evident," says the "Journal," "that the crater had been recently filled with lavas up to the black ledge," and that, as Mr. Goodrich states it in his letter of April, 1825,[1] "the black ledge was made by the crater's being filled to that level." Fortunately the deputation had one in their number, Rev. Mr. Ellis, to make a sketch of the crater, and show precisely what was to be understood by the description. A reduced copy of the sketch as engraved for the "Journal" is here presented, and it is conclusive as to the evidences of a



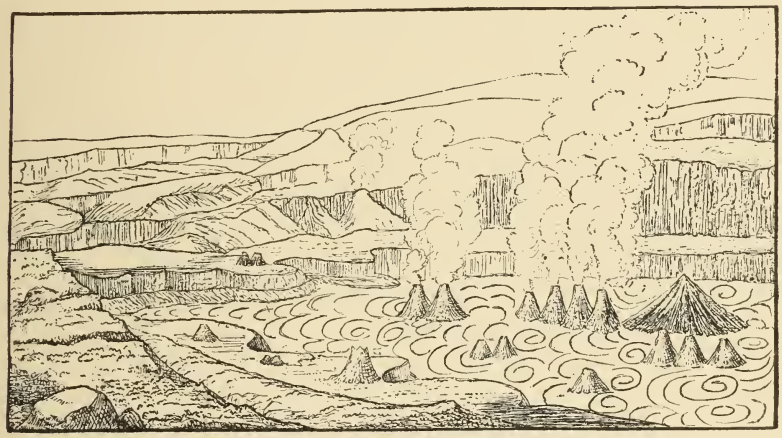
The South End of Kilauea.

recent eruption; for it has nearly the same features as the sketch by Drayton made a little more than six months after the eruption of 1840. And the resemblance extends not merely to the black ledge and the lower pit, but also to the position of the place of greatest activity in the southwest portion. The time of the eruption is inferred from information obtained in Kapapala, a few miles to the southwest of Kilauea, that the steaming chasms, fresh ejections of lavas, and a great sunken area fifty feet deep which the deputation passed near Ponahoahoa were made "two moons" before

[1] Goodrich, American Journal of Science, 1826, xi. 2.

their visit to the place, or, as reported to them at Kearakomo, "five moons;" and they add: "Perhaps the body of the lava that had filled Kilauea up to the black ledge . . . had been drawn off by this subterranean channel."[1] The region is one over which steaming chasms have been made also at later eruptions of Kilauea. Further, Rev. Mr. Bishop was informed by a native, in 1826,[2] that "after rising a little higher the lava would discharge itself toward the sea, as formerly by an underground way," — thus recognizing as a traditional fact what has been fully sustained by later events.

The following is a copy of the view of Kilauea inserted in the English reproduction of the "Journal" called the "Narrative." In spite of the changes it tells the same story as to the deep lower pit and the black ledge.



The Southwest End of Kilauea.

All the changes are unfortunate because they tend to discredit the descriptions. But it is quite evident that the engraver is accountable for them. Two others, besides those mentioned on page 36, are here alluded to, that the reader may draw no wrong conclusions. The lavas of the floor of

[1] Journal of a Tour, etc., pp. 117, 151.

[2] Bishop, Missionary Herald, xxiii. 53, after a visit in 1826.

the crater are represented to be in "tumultuous whorls," to correspond evidently with an expression in Mr. Ellis's description; but the engraver was probably not aware that he had made them hundreds of feet in diameter. The distant southwest part of the crater has its intense fires extinguished, and the wall beyond brought forward and made definite, to the loss of the most characteristic feature of Kilauea.

There is no reason to doubt that the crater, although so little time had elapsed since the eruption, was in a state of intense activity, and yet not so generally flooded with lavas that descent into it was impossible. The description in the "Journal" says: "The southwest and northern parts of the crater were one vast flood of liquid fire, in a state of terrific ebullition. . . . Fifty-one craters, of varied form and size, rose like so many conical islands from the surface of the burning lake. Twenty-two constantly emitted columns of gray smoke or pyramids of brilliant flame [lava-jets ?], and many of them at the same time vomited from their ignited mouths streams of florid lava, which rolled in blazing torrents down their black, indented sides into the boiling mass below." In a night scene "the agitated mass of liquid lava, like a flood of metal, raged with tumultuous whirl," and "at frequent intervals shot up, with loudest detonations, spherical masses of fusing lava or bright ignited stones," some of which projected stones are represented in the sketch (p. 46). Descending to the black ledge (p. 144), they "entered several small craters, . . . bearing marks of very recent fusion, . . . and many which from the top had appeared insignificant as molehills" proved to be "twelve or twenty feet high."[1] They also collected the "hair of Pele," and afterwards found some of it seven miles south of the crater, "where it had been wafted by the winds." Mr. Ellis argues, from the "conical islands," that the boiling caldron of melted lava "was comparatively

[1] Journal, pp. 131, 136, 144.

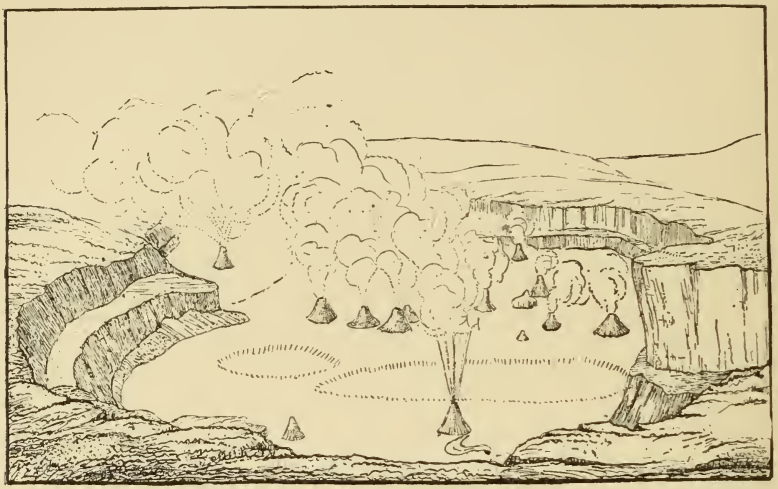
shallow," implying that the cones stood on the solid bottom of the lake.[1] The "Journal," after describing on page 144 long, covered, tunnel-like chambers occupying the emptied interiors of lava-streams, the upper surface rippled, the roof "hung with red and brown stalactitic lava," and "the bottom one continued glassy stream," — words that picture well the hundreds of such tunnel-like caverns in the lava-streams of the mountain, — says that they followed one such covered way "to the edge of the precipice that bounds the great crater, and looked over the fearful steep down which the fiery cascade had rushed," the fall "several hundred feet." The sketch on page 46, from the "Journal," represents rudely such a stream descending the *west* wall (like that of 1832, on the opposite side of the crater); but it is omitted from the sketch in the "Narrative" (see p. 47). It was probably a fact, but was given too great prominence in the view as engraved for the "Journal."

Mr. Goodrich's letter of April, 1825, does not distinguish the events of his first four visits. He observes that in February, 1825, he counted twelve places where the lava was red-hot, and three or four where it was "spouting up lava thirty or forty feet," and mentions the escape of vapors in many places, making "a tremendous roaring," — thus describing fully without naming true "blow-holes" and "blowing-cones." On Dec. 22, 1824, a crater opened in the bottom, where the lavas boiled like a fountain, with jets forty to fifty feet high, and flowed off fifty or sixty rods.

In order to give completeness to the records a copy of the engraving in Ellis's "Polynesian Researches" is introduced on page 50. A painter has intervened between the sketcher and the engraver; and the consequence is easily perceived by the reader without remark. The black ledge is still a char-

[1] Journal, p. 226, and Narrative, p. 237.

acteristic feature, though made very narrow. It is obvious that the high-shooting cone in the foreground, blowing to a height of seven or eight hundred feet (measuring it by the



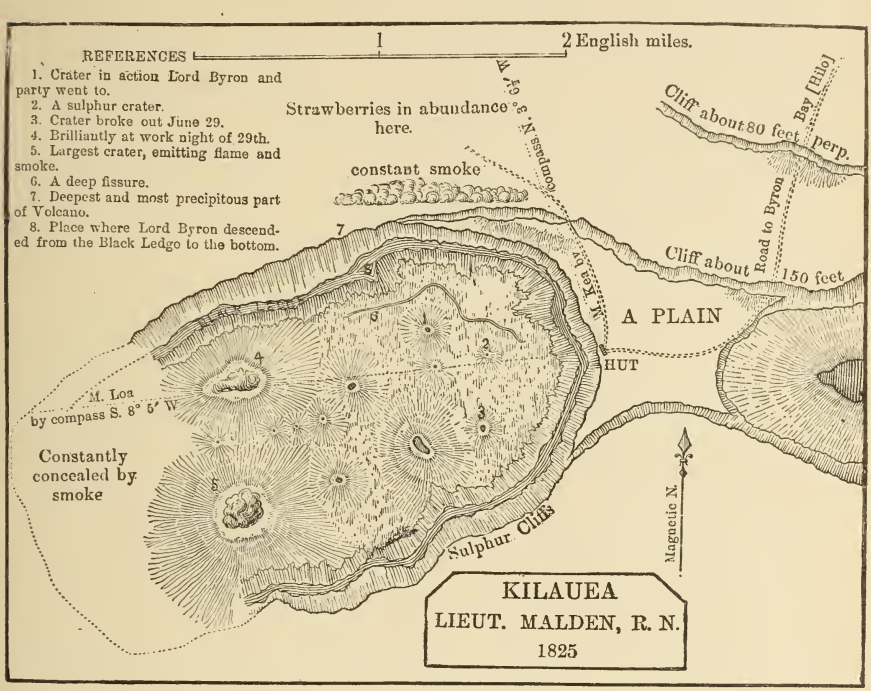
The Volcano of Kilauea.

height of the upper wall), is the artist's idea. It is wholly un-Kilauean, and fundamentally out of place.

Depth of the Lower Pit and Width of the Black Ledge. — The depth of the lower pit in August, 1823, was estimated by the deputation at three or four hundred feet, and the total depth of the crater from seven to eight hundred feet, making the former nearly or quite half the latter. Mr. Goodrich, who was at the crater with the deputation in 1823, and also three times afterward before April, 1825, estimated the whole depth at over a thousand feet, and that of the lower pit at five hundred feet.

On this point and others we have further testimony from a map and a sketch of the crater, besides descriptions, in Lord Byron's "Voyage of the Blonde." Lord Byron's party was at Kilauea in the last week of June, 1825, — nearly two years after Mr. Ellis drew his sketch. The map is from a

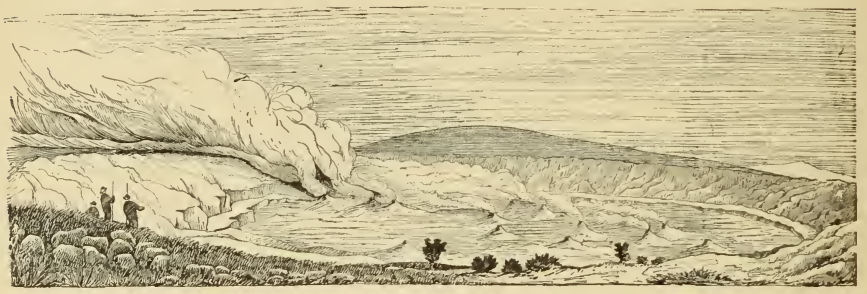
survey by Lieutenant Malden, R. N. The copy here given, reduced one third, represents a narrow black ledge (5) around the lower pit, with a steep wall between them. The


REFERENCES
1. Crater in action Lord Byron and party went to.
2. A sulphur crater.
3. Crater broke out June 29.
4. Brilliantly at work night of 29th.
5. Largest crater, emitting flame and smoke.
6. A deep fissure.
7. Deepest and most precipitous part of Volcano.
8. Place where Lord Byron descended from the Black Ledge to the bottom.
1
2 English miles.
Strawberries in abundance here.
constant smoke
Compass N. 6° E.
Cliff about 80 feet perp.
Bay [Hilo]
Road to Byron
Cliff about 150 feet
A PLAIN
HUT
M. Loa by compass S. 8° 5′ W
Constantly concealed by smoke
Sulphur Cliffs
Magnetic N.
KILAUEA
LIEUT. MALDEN, R. N.
1825

height of this lower wall, or the depth of the lower pit, was estimated by Lieutenant Malden at four hundred feet; and by triangulation he obtained nine hundred feet for the height of the upper wall. The calculation of the latter was based on the angle 5° 55′, subtended by the highest part of the northwest wall (at 7 on the map) from the Hut on the east side, — Lord Byron's place of encampment, — and the distance obtained in his survey of the point 7 from the Hut, namely, 8,209 feet. He states that the result gave 932 feet. But there is some slip in the figures; for the correct height from the data would be 851 feet. The recent government survey of Kilauea makes the distance across 8,750 feet; and using this number, we get 907 feet for the height of the wall. It is therefore probable that 900 feet was about

the height of the upper wall, and that the lower pit two years after Ellis's visit had still a depth of 400 feet.

The sketch of the crater in Lord Byron's "Voyage" was by R. Dampier. It makes the frontispiece to the volume. The following is a copy reduced two thirds. It was evidently taken from the Hut, on the east side of the crater.



KILAUEA.

It shows the lower pit surrounded by a narrow terrace-plain, or black ledge, and the floor with some small cones over its surface, but with the fires chiefly in the southwestern part, — that of Halema'uma'u, — and with the great dome of Mount Loa in the background. Lord Byron's "Voyage" states that "fifty cones of various height appeared below," at least "one half of these in activity;" and Mr. R. Dampier's sketch represents such a scene. Lieutenant Malden's map makes the cones fewer and very broad. His crater No. 5 is probably Halema'uma'u, for the distance from the Hut is right for it; and if so, the part "concealed by smoke" was of much less extent than was supposed by the party.

Rev. C. S. Stewart, the author of a "Journal of a Voyage to the Pacific and Residence at the Sandwich Islands in 1822 to 1825," was with the party from the "Blonde," and confirms the statement in the "Voyage" as to the number of "conical craters" and the position of the chief seat of action in the southwest extremity of the crater. The black ledge is described as covered with tortuous streams of shining lava,

bearing "incontestible evidence of once having been the level of the fiery flood;" and it is added with reference to the lower pit that "a subduction of lava" had "sunk the abyss many hundreds of feet to its present depth." A cone on the bottom, visited by the party, spoken of as "one of the largest, . . . whose laborious action" had attracted attention during the night (No. 1 on Malden's map), was judged to be one hundred and fifty feet high, — "a huge, irregularly shapen, inverted funnel of lava, covered with clefts and orifices, from which bodies of steam escaped with deafening explosions, while pale flames, ashes, stones, and lava were propelled with equal force and noise from its ragged, yawning mouth." The following night crater No. 3 became suddenly eruptive, and a lake of fire (No. 4 ?) perhaps two miles in circumference opened in the more distant part.

The black ledge is represented as narrow in all the published sketches, but most so in Malden's map, and in the view in Ellis's "Polynesian Researches," which had the benefit of improvements from a professional artist. As the latter work was published five years after the "Voyage of the Blonde," it may be queried whether Mr. Howard, the painter, derived any ideas from Dampier's sketch; but the following facts are rather against this: Mr. Goodrich, in his letter of 1825, who shows careful work in his measurements of the circumference of the crater *with a line*, remarks that the ledge "is like a stair, although it is half a mile wide some part of the way."[1] By his measurements, in which he was assisted by Mr. Chamberlain,[2] he made the circumference of Kilauea seven and a half miles, which is the length on the recent government map, and that of the black ledge (going only half-way around and estimating for the rest) five and a half miles, which also was probably very nearly right.

[1] Goodrich, American Journal of Science, 1826, xi. 2.

[2] Rev. L. Chamberlain, Ibid., and Missionary Herald, 1826, xxii. 42; Ellis's Polynesian Researches, iv. 253; Philosophical Magazine, September, 1826.

Lord Byron, on his descent into the pit, went from the northeast to the northwest side, and states with regard to the width of the ledge — probably the part on the north side, or that passed over — that it varies from four or five feet to upwards of twenty, which supports the evidence from the map and sketch in his "Voyage;" and Mr. Stewart says that it was in some places many rods and in others a few feet wide. A direct measurement of the southwest part, toward the sulphur banks, was made in June, 1824, by Rev. E. Loomis, with the result "nearly fifteen rods wide,"[1] — which is about two hundred and fifty feet.

It will be observed that, in the above citations from Mr. Ellis and other early writers on Kilauea, the only heights of ejections of lava mentioned are thirty to forty and fifty feet, and of cones twelve feet, twenty feet, and for "one of the largest cones" one hundred and fifty feet, — which are common facts of later time down to the present. The language of descriptions is sometimes strong, but the figures are correct.

This close correspondence between the heights and character of ejections given in the earlier accounts and those of recent years is interesting, inasmuch as it proves long-continued uniformity with regard to kind and quality of work, even to the blowholes. The activity was, however, greater and more general than has been witnessed for many years. There are exaggerations, but they are mostly confined to the pictures and to some of the general descriptions. The *estimates* made were usually below the truth, from honest caution.

Progress in the Filling of the Lower Pit. — As early as February, 1825, Mr. Goodrich stated, in view of the overflows he had observed, and the making of a "mound" over sixty feet high in six weeks, that the pit had begun to fill

[1] Memoir of W. T. Brigham, p. 407.

up;[1] and in his letter of Oct. 25, 1828,[2] he made the pit to have diminished in depth since August, 1823, by three or four hundred feet. A year later, Oct. 25, 1829, Mr. Stewart found the lavas, according to his description,[3] still two hundred feet below the level of the black ledge, — which implies a filling of four hundred feet, if the depth in 1823 was six hundred feet, and of six hundred if eight hundred feet deep. He states that although the crater was comparatively quiet, the bottom was crossed by a chain of lava-lakes, one of them a mile wide, throwing up masses of lava fifteen to twenty feet; and that there were also six cones in action in the lower pit and one on the black ledge. Here again the height of the ejections mentioned is small. In October, 1830, the black ledge was still distinct.[4]

But in November of 1832 Mr. Goodrich writes that in the preceding July he visited Kilauea, and found evidence that "the crater had been filled up to the black ledge and about fifty feet above it, — about nine hundred feet in the whole," since he first visited it (in 1823).

Eruption of 1832. — Mr. Goodrich found at his November visit that an eruption had taken place; for he continues: "It had now again sunk down to nearly the same depth as at first, leaving as usual a boiling caldron at the south end. The inside of the crater had entirely changed. . . . In January preceding — about the 12th as nearly as I can ascertain — the volcano commenced a vigorous system of operations, sending out volumes of smoke; and the fires so powerfully illumined the smoke that it had the appearance of a city enveloped in one general conflagration. A day or two fol-

[1] J. Goodrich, letter of April 20, 1825, American Journal of Science, 1826, xi. 2.

[2] Ibid., 1829, xvi. 345.

[3] C. S. Stewart, Visit to the South Seas (New York, 1831), including an account of a visit to Kilauea Oct. 9, 1829; and American Journal of Science, 1831, xx. 229.

[4] H. Bingham, Residence in the Sandwich Islands, p. 387.

lowing smart shocks of earthquakes commenced, six or eight a day. . . . The earthquakes rent in twain the walls of the crater on the east side from the top to the bottom, producing seams from a few inches to several yards in width, from which the region around was deluged with lava. . . . The chasms" passed "within a few yards of where Mr. Stewart, Lord Byron, myself, and others had slept," — the Hut on Malden's map; "so that the spot where I have lain quietly many times is entirely overrun with lava." Descending into the crater and going "to the south end, I found myself on the brink of a burning lake, — an opening in the lava sixty to eighty rods long, and twenty or thirty wide, — the whole mass of liquid and semi-liquid lava in which, about twenty feet below the brink, was boiling, foaming, and dashing in billows against the rocky shore. The mass was in motion, running from north to south at the rate of two or three miles an hour, boiling up as a spring at one end and running to the other."

Depth of the Lower Pit after the Eruption.— Mr. Goodrich's statements above cited would make the depth of the lower pit after the eruption of 1832 nearly nine hundred feet, and of the crater from top to bottom seventeen hundred and fifty feet. There is no published account furnishing data for correcting this estimate. By letter from Mr. W. D. Alexander, Surveyor-General of the Hawaiian Islands, dated March 2, 1887, I learn that his father, Rev. William C. Alexander (who arrived at the Sandwich Islands in 1832) visited the crater Jan. 12, 1833, four months after Mr. Goodrich's visit, and in his private diary gives the depth of the crater as two thousand feet. This tends to confirm Mr. Goodrich's numbers, although only a rough estimate. He says nothing of any black ledge, except of that at the bottom of the two thousand feet; and this leads to the inference that the ledge was quite narrow, as in 1823.

There is other full evidence from Mr. David Douglas's "Journal" of the existence of a lower pit and black ledge after the spring of 1832, and thereby of the down-plunge, accompanying a discharge of the lavas.[1] On Jan. 22, 1834, Mr. Douglas made careful barometric measurements of the crater, all the details of which, with the calculation, are given in his letter to Captain Sabine. He obtained for the depth to the black ledge, on the highest northwest side, 715 feet, and to the bottom of the lower pit 1,077 feet, as a mean of two calculations. This makes the depth of the lower pit at that date 362 feet, in addition to which he says that there were forty-three feet more to the surface of the liquid lavas.

We thus know that the down-plunge was a fact; and we have proof further from the measurements of Mr. Douglas that the lower pit was larger both as to depth and breadth than that of 1840. Hence the eruption of 1832 — instead of being "a very small one, only remarkable from the fact that the fissure from which it emanated opens at a level of more than four hundred feet above the present lava-lakes," with, "so far as known, . . . no sympathy . . . within the lavas of Kilauea" — was one of Kilauea's greatest, although not registered, so far as known, in any outside stream of lava.

Condition of the Crater; Filling of the Lower Pit. — Some facts are cited on the preceding page from Mr. Goodrich with regard to the condition of the bottom of the crater after the eruption. Mr. Alexander, while in the crater four months later, found the lake in the southwest end of the lower pit, "the principal furnace, not in lively action," and ascended much disappointed; but by the time he had reached the summit "the grand crater commenced furious action,

[1] Memoir of D. Douglas, Companion of the Botanical Magazine, 1836, ii.; and Letter to Captain Sabine, May 3, 1834 (see p. 38).

spouting with a roaring sound streams of melted lava far into the air." The next day he went again to the bottom, and direct to the great boiling caldron two and a half miles distant," and found it "three thousand feet long and one thousand feet wide, tossing its fiery surges forty or fifty feet into the air." He went to the brink of the lake, but left it on account of the fumes, and three minutes afterward the spot was covered with the lavas of an overflow, "which," he says, "seemed to pursue us as we hastened away." It is important to observe that uniformly the "far into the air" and similar expressions in the general descriptions of travellers become when put in figures not far from thirty, forty, or fifty feet of actual height.

Mr. Douglas, whose visit was in 1834, reports that he found two great boiling lakes in the crater, — a northern, 319 yards in diameter, and a southern, 1190 × 700 yards in area, heart-shaped in form. The great southern lake was "at times calm and level, the numerous fiery-red streaks on its surface alone attesting its state of ebullition, when again the red-hot lavas would dart upwards and boil with terrific grandeur, spouting to a height which from the distance at which I stood (on the west wall) I calculated to be from twenty to seventy feet. Close by stood a chimney above forty feet high, which occasionally discharged its steam as if all the steam-engines in the world were concentrated in it," — a good description of a blowing-cone, though the name had not yet been used. There were other chimneys over the bottom, some active and others comparatively quiet. In each of the large lakes the lavas had an apparent movement southward, the velocity of which Mr. Douglas measured (by throwing on a block of lava and seeing how long it took to go one hundred yards), and found it to be nearly three and a quarter miles an hour.[1]

[1] Mr. Douglas's testimony with regard to the Hawaiian volcanoes has been doubted because of his incredible account of what he saw at the summit crater in a

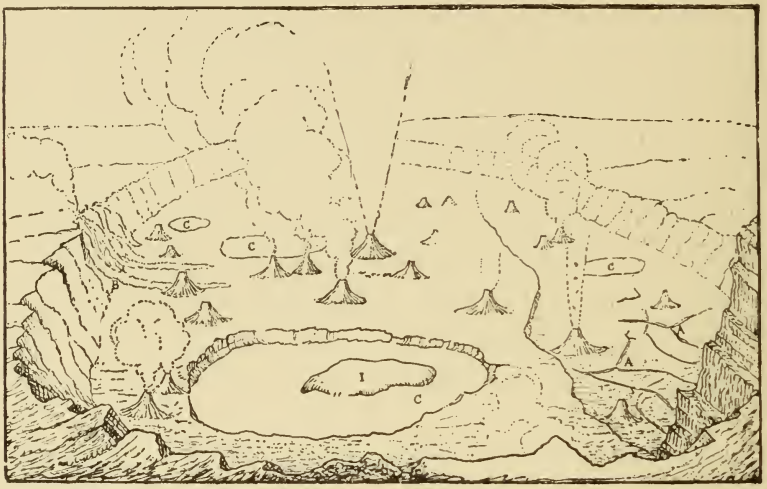
Thus the filling of the lower pit was again in progress; and according to information from Mr. S. N. Castle, of Honolulu, the obliteration was nearly complete by the latter part of August, 1837. Mr. Castle reports that he found cones active in all parts of the crater.

On May 8, 1838, Kilauea was visited by Captains Chase and Parker, and an account of their observations was written out from their statements by Mr. E. G. Kelley, submitted to them for approval, and afterward published in the "American Journal of Science" for 1841,[1] with a plate from their sketches, but redrawn, unfortunately, by a New Haven artist who evidently had Vesuvius in his thoughts. An outline copy is here introduced. It was taken at the south end looking northeastward, and has the great South Lake in the foreground. The important fact is registered in it that the black ledge was already nearly buried. There is none on the west or north side; and to the left, instead of a black ledge, there is a depressed plain, forty feet below the general level; part of it (AA) was flooded by lavas after having been passed over by the party. The crater was unusually active; there were twenty-six volcanic cones, twenty to sixty feet high, eight of them throwing out cinders, red-hot lava, and steam, and six lakes of lava including the Great Lake (C), the last "occupying more space than all the rest."

letter to the eminent botanist, Dr. Hooker. But I find that injustice has been done him. His "Journal" of his visit to the summit, evidently written by him at the time of his observations, represents the crater as having been long quiet. While at Honolulu, over three months later (May 3), he wrote Captain Sabine on his various physical investigations and barometric measurements, and gave him the same facts as to the summit crater that he has in his "Journal," and partly in the same words. Only three days later (May 6) he wrote his letter to Dr. Hooker, — a reasonable letter in all parts, excepting its description of the terrific activity and immense size of the Mount Loa crater. His words indicate a mixing up and magnifying of what he had seen at the Kilauea and summit craters, which can be explained only on the ground of temporary hallucination. He may have dined that day with his friend the British consul. Mr. Douglas was an excellent Scotchman, and all the rest of his writings are beyond questioning.

[1] American Journal of Science, 1841, xl. 117.

Not far from the centre of the Great Lake an island (I) of black solid lava "heaved up and down in the liquid mass," and "rocked like a ship on a stormy sea." This is the first mention of a "floating island." The descending streams at



KILAUEA, from the south end.

B are described as streams of sulphur; but as this is not possible, they were probably lava-streams in part colored yellow.

We have still another account for the same year; it is that of Count Strzelecki, who was at the crater in August or September, and published his notes in his work on "New South Wales and Van Diemen's Land," in 1845. He made some barometric measurements over the region, and determined the height of the north-northeast wall down to the "boiling surface of igneous matter" to be six hundred feet, and makes no mention of a black ledge. He describes six craters with boiling lavas, four of which were only three or four feet high, a fifth forty feet, the sixth one hundred and fifty feet. He states that the first five contained twelve thousand square feet each; while the sixth — which he says is called "Hau-mau-mau" — contained nearly a million. He

alludes plainly to the ebullition over this great lake in the expression "ceaseless impetuosity and fury." He says that "the lava sank and rose in all the lakes simultaneously," which is not always true.[1]

Still further evidence as to the obliteration of the black ledge is supplied by Capt. John Shepherd, R. N., who visited Kilauea on Sept. 16, 1839. Captain Shepherd descended into the crater, and visited several cones and small lakes on his way to the Great Lake. He speaks of the black ledge as "obliterated;" of cones twenty to thirty feet high, whence issued vapors and lava with loud detonations; of a lake of lava toward the *east* side one mile long and half a mile wide within a cone a hundred feet high, from the summit of which he saw the expanse of liquid lava "in violent ebullition." He also mentions that the lavas had an apparent flow from south to north, and adds, "caused by the escape of elastic fluids, throwing up the spray in many parts thirty to forty feet."[2]

Eruption of 1840. — The eruption of 1840 had no witness from among the foreign residents of the islands. Mr. Coan was absent from Hilo at the time on a mission visit to Oahu. He states in his letter on the event, dated September, 1840,[3]

[1] Count Strzelecki's note in the Hawaiian "Spectator" occurs in the number for October, 1838, which number also states that he was visiting various portions of the Pacific in H. B. M. S. "Fly." It differs widely from the report in his own work, in making the area of the largest lake three hundred thousand square yards, and those of the smaller "about fifty-seven hundred square yards each." His volume is the later publication, and should set aside the newspaper note. Count Strzelecki in this volume describes the terraces around the Kilauea crater as vast platforms; makes the height above the sea-level of the north-northeast side of Kilauea, two paces from the edge of the precipice, 4,109 feet above tide-level, and 600 feet above the fires below; and observes that this is 950 feet below the brim of the *ancient* crater, the highest point of which he made 5,054 feet, and its circuit twenty-four miles. He thought he saw evidence that this greater crater was formerly brimful of molten lava. If this highest point was, as is probable, that now highest on the west side, his observed height would imply a large subsidence.

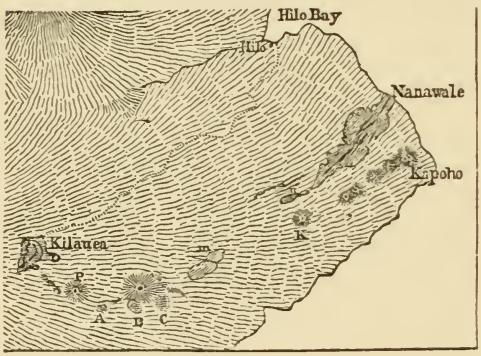
[2] London Athenæum, Nov. 14, 1840, p. 909.

[3] Missionary Herald, xxxvii. 283.

that "on the testimony of many natives" for a week previous to the eruption, in the latter part of May, the interior of Kilauea was "one great sea of liquid lavas," and that the ground about Kilauea so trembled from the action below that the islanders avoided the path along the verge of the crater.

On his first visit in September, three months after the eruption, he found the crater with a deep lower pit and a terrace-plain or black ledge around the whole interior. Drayton's sketch (Plate II.), though made four months later, represents closely the scene.

Mr. Coan gathered facts showing that the eruption began on May 30, made itself apparent at intervals down the eastern slopes of the mountain, finally broke out as a stream twelve miles from the coast, and flowed into the sea just south of Nanawale; and that the flowing continued for three weeks. There was no earthquake, no shaking of the mountain. At Hilo not the faintest rumbling was heard or felt, and only slight quiverings to the north. A light was seen in the distance; but there were no inhabitants in the region, and it was supposed to be a jungle on fire. The lavas appeared first in a small pit-crater five miles southeast of Kilauea (A. in the accompanying map, which is a reduced copy of part of a large map in the Atlas of Wilkes's "Narrative"). The natives stated that the lavas rose to a height of three hundred feet in the crater, and this was confirmed by the scoria within it. Next followed small ejections over the surface near by, where other fissures had opened, and simultaneously the lava of the crater



sunk and disappeared. Other small openings and ejections occurred near C, *m*, and *n*; and finally, on June 1, began the large flow that was continuous to the sea, which it reached on June 3, extending the coast-line outward nearly a fourth of a mile, and so heating the waters that for twenty miles the shores were strewn with dead fish.

The place of final outflow was twenty-seven miles from Kilauea, and eleven from the sea; and its height, according to Wilkes, 1,244 feet above tide-level.

The flowing lava swept away forests in its course, at times parting and enclosing islets of earth and shrubbery, and at other times undermining and bearing along masses of rock and vegetation on its surface. It plunged into the sea with loud detonations. The burning lava, on meeting the waters, was shivered like melted glass into millions of particles, which were thrown up in clouds that darkened the sky and fell like a storm of hail over the surrounding country. The light "was visible for over a hundred miles at sea, and at the distance of forty miles fine print could be read at midnight."

The author was over the region in the following November. The stream consisted largely of the smoother lava or pahoehoe, with twisted and ropy surface, as usual; but there were large areas of *aa*, in which huge blocks were piled together, and in some places slabs were laid with much regularity against one another. Here and there were miniature cones a few yards in height, out of which the lavas had spouted for a while after the stream had flowed on. Many fissures and caverns were sending up hot vapors, and in some the rocks were yet glowing within a few feet of the surface.

The islets of forest-trees in the midst of the stream of lava were from one to fifty acres in extent; and the trees still stood, and were sometimes living. Captain Wilkes describes a copse of bamboo which the lava had divided and surrounded; yet many of the stems were alive, and a part of the

foliage remained uninjured. Near the lower part of the flood the forests were destroyed for a breadth of half a mile on either side, and were loaded with the volcanic sand; but in the upper part Dr. Charles Pickering of the Expedition Scientific Corps (both botanist and zoölogist) found the line of dead trees only twenty feet wide. The lava sometimes, as in other eruptions, flowed around stumps of trees; and as the tree was gradually consumed it left a deep cylindrical hole, either empty or filled with charcoal. Toward the margin of the stream these stump-holes were innumerable; and in many instances the fallen top lay near by, dead but not burned. Dr. Pickering also states that some epiphytic plants upon these fallen trees had begun again to sprout. The rapidity with which lava cools is still more remarkably shown in the fact that it was found sometimes hanging in stalactites from the branches of trees; and although so fluid when thrown off from the stream as to clasp the branch, the heat had barely scorched the bark.

The lava, as stated by Wilkes, issued from several fissures along its whole course, instead of being an overflow from a single opening.

At three spots on the coast, probably over three opened fissures, the sands continued to be thrown up until as many

Tufa Hills, Nanawale.

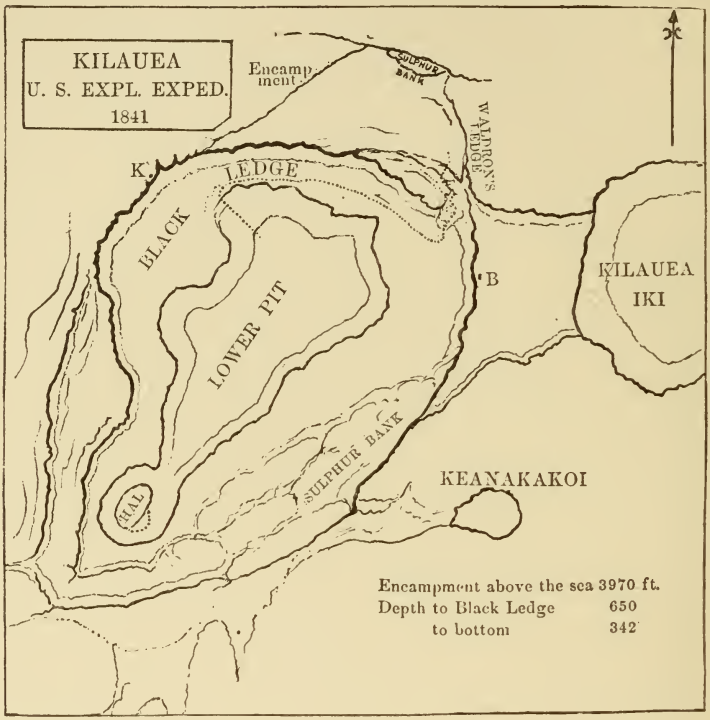
rounded or nearly conical elevations were formed, the largest of which was found to be two hundred and fifty feet in height, and the smallest about one hundred and fifty feet. They consist of a finely laminated tufa, like tufa-craters. The above figure shows the appearance of the hills at the time of the author's visit in November of 1840.

These sand-hills are examples of elevations thrown up suddenly over fissures of eruption. They consist of a rusty yellow tufa, distinctly and finely laminated. The sea was already encroaching on them in the autumn of 1840, and had exposed the regular stratification of the interior, showing a steep inclination of the layers outward. Not a trace of tilting took place in the rocks beneath; the hills are simple cones of eruption formed of ejected cinders. The sands are said to have been thrown out from the centre of each hill while in progress; yet there was no cavity at top. As the molten lava met the sea there was a violent explosion, and an ejection of fragments which fell around the centre of eruption; and owing to the water which ascended and descended with them, the structure became laminated. The yellow color of the tufa is owing to the action of the steam and water on the augitic and chrysolitic sands, reducing some part of the iron to a hydrate.

The time of origin of the several pit-craters to the southeast of Kilauea is not known. One of them, Makaopuhi, has the western half about nine hundred feet in depth, according to Rev. E. P. Baker, and the eastern only half this depth, — the latter level answering apparently to a black ledge or terrace.

Form and Depth of the Crater after the Eruption of 1840. — The study of the crater by the Wilkes Exploring Expedition was begun in December, 1840, — more than a month after the author's visit, — and completed in January, after the pendulum experiments had been made at the summit of Mount Loa. The accompanying map is a reduced copy of that published by Captain Wilkes. The scale is five thousand feet to the inch. K is for Kamohoalii; and B the position of Byron's Hut. It will be observed that it has adjoining it on the east two smaller pit-craters, — Kilauea-iki, or Little Kilauea, and Keanakakoi, — both inactive in 1840, and

of unknown time of origin.[1] Wilkes's map makes the wall of the lower pit much too sloping, and the neck between the



main body of the lower pit and the area of the Great Lake, Halema'uma'u, far too narrow. Both are better represented in Drayton's sketch, on Plate II.; but the latter errs a little

[1] The size of these lateral pit-craters is better mapped on Plate III. Kilauea-iki, according to Mr. Dodge's recent measurements, is 3,300 feet from east to west, and 2,800 feet from north to south, and has a depth of 749 feet, or the bottom is 867 feet below the Volcano House datum. Keanakakoi is 1,600 feet long, 1,100 feet wide, and approximately 400 feet deep. Both have nearly vertical walls.

The name "Keanakakoi" (or Keana-ka-koi), applied on the Hawaiian government map to the small crater east of the southern half of Kilauea, signifies, as I was informed by an intelligent native, the "chipping-stone pit," and refers to the fact that formerly a very compact grayish lava was obtained at its bottom and used there for the manufacture of stone implements. No such stone or manufacture has ever existed at Kilauea-iki. This appears to settle the question raised by Mr. Brigham as to the correct application of the latter name. The crater has now a bottom of very smooth recent lava, which our guide stated had been ejected eight or ten years back: its ejection may have occurred, therefore, at the time of the eruption of Kilauea in 1879.

on the other side, as the walls are too free from debris. (For further remarks on the map see page 135. A dotted line is added in the northeast corner to indicate the place of descent.)

With regard to the depth of the crater, we find, as the first statement about it in Wilkes's Narrative,[1] that the "black ledge surrounds it [the crater] at the depth of 660 feet, and thence to the bottom is 384 feet." Four pages beyond, it is added that "the black ledge is of various widths, from 600 to 2,000 feet." Later in the volume measurements by Lieutenants Henry Eld and Thomas A. Budd are also given. Lieutenant Budd made the depth to the black ledge 650 feet, and thence to the bottom 342 feet, "whence the total depth 992."[2] Again, Lieutenant Eld, it is observed,[3] was instructed to make the measurement of the depth, "as I was desirous of proving *my own* as well as Lieutenant Budd's observations;" and then follows the remark, "The measurements coincided within a few feet of each other." Had the precise numbers obtained by Lieutenant Eld been reported we might be able to remove the doubts left by the varying statements. But the fact that Lieutenant Budd's results are inserted by Captain Wilkes on his own map of the crater is a strong reason for believing that the coincidence was between the results obtained by the two lieutenants.

Condition of the Crater at the Time of the Author's Visit in November, 1840.—Although the crater had been discharged but six months before, the Great South Lake, Halema'uma'u, was again in full ebullition over its surface, an area of one thousand by fifteen hundred feet, according to measurements by Captain Wilkes. Besides, there were two small boiling lava-lakes.

[1] Narrative of the Exploring Expedition, iv. 123.
[2] Ibid., p. 175.
[3] Ibid., p. 179.

Still, to the spectator on the northern brink of the pit, all was marvellously quiet. The lofty walls were horizontally stratified, much like those of limestone along some river-gorges, and, in the view, were as free as the latter from scoria and all else of volcanic aspect. The interior of the crater, an area two and a half miles long, covering nearly four square miles, was a desolate scene of bare rock. Instead of a sea of molten lava "rolling to and fro its fiery surge and flaming billows," the only signs of action were in three spots of a blood-red color which were in feeble but constant agitation, like that of a caldron in ebullition. Fiery jets were playing over the surface of the three lakes; but it was merely quiet boiling, for not a whisper was heard from the depths. And in harmony with the stillness of the scene, white vapors rose in fleecy wreaths from the pools and numerous fissures, and collected over the large lava-lake into a broad canopy of clouds not unlike the snowy heaps that lie near the horizon on a clear day, though changing rapidly in shape through constant accessions of cloud material from below.

When on the verge of the lower pit, a half-smothered, gurgling sound was all that could be heard. Occasionally a report like musketry came from the depths; then all was still again, except the stifled mutterings of the boiling lakes.

In a night scene from the summit the large caldron, in place of a bloody glare, now glowed with intense brilliancy, and the surface sparkled all over with shifting points of dazzling light like "a network of lightning"[1] occasioned by the jets in constant play; at the start of each the white light of the depths breaking through to the surface.

A row of small basins on the southeast side of the lake were also jetting out their glowing lavas. The two smaller lakes tossed up their molten rock much like the larger, and

[1] A comparison made by my friend Dr. Charles Pickering, a man of very exact observation and measured words.

occasionally there were sudden bursts to a height of forty or fifty feet. The broad canopy of clouds above the pit, and the amphitheatre of rocks around the lower depths were brightly illumined from the boiling lavas, while a lurid red tinged the more distant walls, and threw into varying depths of blackness the many cavernous recesses.

The next night streams of lava boiled over from the lake, and formed several glowing lines diverging over the bottom of the crater. Toward morning there was a dense mist, and the whole atmosphere seemed on fire. The lakes were barely distinguished through the haze, by the spangles on the surface that were brightening and disappearing with incessant change.

Reaching the black ledge we came upon the scene of the recent fires and lava-flows, although the boiling pools were still three hundred and forty feet below. Streams of hardened lava with their tortuous windings covered its surface, some spreading far and wide and ending in a rolled margin against the base of the outside walls of the crater, and some twisted into ropes or ropy lines, or reaching out in rounded knobs. Others, of less extent, surrounded an oddly shaped cone, a few yards in height, which small worming streams and smaller driblets of lava had raised. These features were testimony to the great lava-floods that spread over the whole crater, even the black ledge, before the eruption of the preceding June. Other reminders were the many dark chasms along the margin of the black ledge, some opening to depths of hundreds of feet, and letting up torrents of hot air or suffocating fumes of sulphur. In several places acres of the ledge were tottering ready to fall; and twice, while among the chasms, long-continued rumbling sounds broke the silence of the pit, showing that the engulfing or down-plunging of the walls, that began with the discharge of June, was still in progress.

The great subsidence of nearly four hundred feet at the

time of the eruption, making the lower pit, generally gave the pit vertical walls, with no slopes except such as were formed of fallen masses of rock. But on the northwest side, the outer part of a great block five hundred yards along the ledge and four hundred yards in mean width, and hence two hundred thousand square yards in area, sank down the four hundred feet so as to make a sloping plane from the top of the ledge to the bottom of the pit. A broad fissure divided the sunken, sloping mass from the black ledge, and other fissures intersected its surface. A descent into the lower pit along any part of the vertical walls was dangerous; but here it was easy.[1]

Over the solidified lava-streams of the bottom, as well as the black ledge, the tread made the lava crackle, as if it were nothing but the loosest of fragile scoria. The crackling was due to a shining, glassy scoriaceous crust, two to four inches thick, that was crushed under the foot, and was easily peeled off from the more solid rock of the lava-stream. Few visitors to the crater find out that there is any other kind of lava in the crater besides this shining and often iridescent crust. It was found to be only the scum of the boiling lava-lakes, — the frothy part, which each stream bore off, like that on a stream from a pot of boiling molasses.

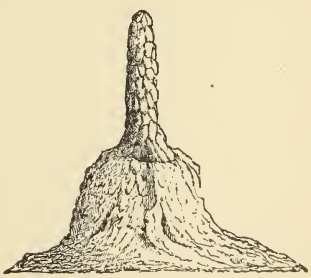
Over the eastern of the two small lava-lakes, the first visited, the lava-jets darted to a height of ten or a dozen yards, and fell again into the lake or upon its sides. There was no inconvenience or danger in standing within four or five feet of the edge of the basin. The formation of Pele's hair, or capillary volcanic glass, was going on at the time; and the spun glass covered thickly the surface to leeward of the lake, where it lay like mown grass. On watching the

[1] It is indicated as the place of descent on the Wilkes map (p. 66). In Drayton's view (Plate II.) the line of the sloping plane was coincident with the line of vision, and hence it does not appear.

operation a moment it was apparent that it proceeded from the jets of liquid lava thrown up by the process of boiling. The winds carried off the spun glass, and laid it down over the surface to leeward, the heavy or loaded end going down first. It appeared, at the time, as if the wind carried off small points of the jetted lavas, and thus drew out the glassy hairs; but others have since shown that the hairs are drawn out when the projected lava, in its ascent, becomes divided into a succession of clots, the hairs being spun as the pieces pull apart, and that the wind serves only as a transporter.

The overflowing of the lava-lake — a common event for the smaller lakes as well as the large — had made a low cone about it, exemplifying the process of overflow or superfluent eruptions characterizing the early period of a volcanic mountain. One such cone of great breadth over the centre of the floor, with a large crater at top but then extinct, had a height of about one hundred feet. The lavas of the floor covered caves of various sizes, and the roofs afforded stony stalactites, some of them of ordinary tapering shapes and others of a slender cylindrical form not larger than a quill and partly hollow.

A few hundred yards from the eastern lava-lake there stood a singular spire of lava, like a petrified fountain. A column of hardened lava-drops had been raised on a rudely shaped conical base, having a height in all of about forty feet. It had been formed over a small vent, out of which the liquid rock was shot up in driblets and small jets, — making one of the fantastic driblet-cones, as the author has since called them, — the result of blowing-hole action. It is an interesting example of a cone of 90° on one of 40° to 70°, made out of



Driblet-cone, November, 1840.

descending lavas, but lavas in drops, the drops in succession adhering to one another; the aperture from which those of the column were thrown out was close by its base.

The surface of the Great Lake, at the time of the author's exploration of the bottom, was fifteen or twenty feet below its banks, and the height of the jets appeared to be nearly as many yards. The surface lavas, with the playing jets, had apparently, as reported by Douglas, a flow to the southwestward. It looked as if a great lava-stream came up to the surface for a moment and flowed on; but it was apparent that it was due to the process of ebullition, — the lavas raised in the hotter portions flowing off to the cooler side.

One of the most striking sights in the crater was that of the cooled and hollow streams of lava coming down the steep walls just south of the usual place of descent. They were those of the eruption of 1832, which flooded the plain above, including the site of Lord Byron's "Hut," and which also plunged into the crater, besides escaping from fissures in the wall. The angle of descent of the streams was about 35°; and yet the streams were continuous. The ejection had been made to a height of four hundred feet at a time when the pit below was under boiling lavas and ready for discharge. Elsewhere about the upper walls, and also about those of the lower pit, no scoria was seen. The surfaces of walls are those of fractures, brought into sight by subsidences; and the rocks of the layers were as solid as the most solid of lavas. Moreover, no scoria intervened between the beds of lava even in the walls of the lower pit, each new stream having apparently melted the scoria-crust of the layer it flowed over; and no beds of cinders or volcanic ashes were anywhere to be seen in alternation with the beds of lava. While the cooled lava-streams over the bottom were of the smooth-surfaced kind, and would be called pahoehoe, there was the important distinction into streams having the scoria-crust just mentioned, and those having the exterior solid with no sep-

arable crust, — facts that pointed to some marked difference in conditions of origin.

Condition in January, 1841. — In January, on the 16th, as observed by Captain Wilkes, one of the small lava-lakes, called Judd's Lake, sent forth a great stream over the bottom of Kilauea, and on the night after the following day, Hale-ma'uma'u, the Great Lake, overflowed. The next morning the lavas had sunk one hundred feet. On the 26th Dr. Pickering found the surface much depressed and in ebullition throughout; yet "Judd's Lake was at the same time overflowing its banks." Dr. Pickering concluded, from his observations at this time and in December, that during the intervening month the bottom of "the lower pit had been raised at least fifty feet."

The crater had then (as shown on the map, p. 60) two sulphur-bank regions. One was situated on the southeast side of the crater, where the rocks of the wall had been crumbled to an earthy slope in consequence of their decomposition by the hot acid fumes. Fine crystallizations of sulphur were constantly forming through condensations beneath an outer crust of the earthy surface; and with the sulphur there was some gypsum, a little alum (alumina sulphate), some ammonium sulphate, and traces of blue vitriol or copper sulphate, the last indicating the probable presence, in the depths below, of the common copper pyrites or chalcopyrite.

Another larger sulphur-bank region — a true solfatara — occupied the eastern part of the broad depressed area at the northeast end of the crater, — an area intersected by many profound chasms emitting hot air and water vapor, and some of them also fumes of sulphurous acid. Incrustations of the blue copper sulphate were obtained also at this place. Toward the margin on this side of the pit large sections of the walls had subsided; and the way down into the pit was along such sunken blocks and among the steaming chasms.

3. Kilauea from January, 1841, to 1868 inclusive.

The history of Kilauea thus far presented includes three great eruptions within the seventeen and a half years between the early part of 1823 and the summer of 1840, with intervals of eight to nine years. It also indicates that the method of change was, in a general way, alike for each interval, from the emptied state of the pit to that of high-flood level preparatory to discharge; and alike in the down-plunge of the floor consequent on the discharge. Further, the various accounts agree in referring the filling of the pit to outflows of lavas from lava-lakes, cones, and fissures over the bottom of the crater, and in mentioning no facts that point to other concurring means.

During the following twenty-eight-year period, from 1840 to 1868, these several subjects received not only contributions of new facts, but the most fundamental of them, on the method of filling the pit, facts enough for a widened and apparently final explanation. Even within the first six years of the twenty-eight the demonstration was made out, though not published until 1851. The only down-plunge of the floor in this period, producing a lower pit, occurred at its close in 1868.

(1) *Changes in the Crater from* 1841 *to* 1849. — The changes after the year 1840 went forward in the usual quiet way, varying much from time to time, but on the whole with some increase in activity.

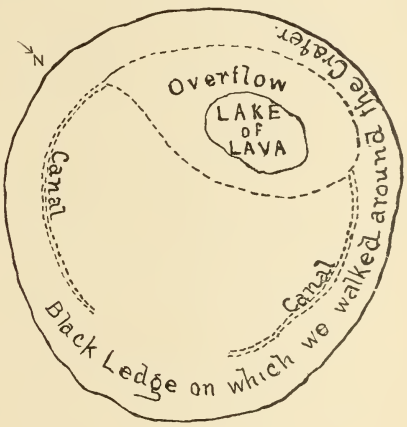
In July, 1844, according to a letter from Mr. Coan,[1] the

[1] The letter of Mr. Coan has not been published entire, and the author is indebted to his son, Mr. T. Munson Coan, for a copy received in April, 1888. Some extracts from a letter on the same subject are contained in the author's "Exploration Expedition Report," p. 193. The complete letter, in connection with the observations of Mr. Lyman above reported, enables the author to correct the note about the canals on page 84 of the "American Journal of Science" for July, 1887.

Great Lake, Halema'uma'u, overflowed its margin on all sides, "spreading out into a vast sea of fire, filling the whole southern part of the crater out to the black ledge on either side, and thus obliterating the outlines of the caldron." Moreover, the lavas flowed northward and northeastward "in two deep canals five to fifteen rods wide, one hundred feet deep, and two miles long," — one by either margin of the lower pit at the base of its walls; and "the two came within half a mile of meeting under the northern wall of the crater." [1] In one of these canals the liquid lava plunged down a precipice of some fifty feet, forming "a fiery cataract of indescribable grandeur."

The facts were also observed by his son, Mr. Titus Munson Coan, and a similar record made at the time. The latter mentions also a small lake in the floor of the pit toward the middle of the west side.

A diagram by the Rev. Mr. Coan accompanies the letter. It represents the canals at the base of the wall bounding the lower pit, and situated close by the black ledge, on which, as is recorded on the map, the two walked at the time around the crater besides also crossing the lower pit.



Canals five to fifteen rods or eighty to two hundred and fifty feet wide, could not be ordinary fissures; and their position along the sides of the lower pit at the foot of the enclosing walls, their depth, the cascade of fifty feet, their great length, the two nearly encircling the lower pit, were at the time without explanation. The depth of the lower pit is not stated.

[1] Coan, Life in Hawaii, 1882, p. 263.

Two years later, in June of 1846, Mr. Coan reported[1] that "the repeated overflowings had elevated the central parts of the crater four or five hundred feet since 1840, so that some points are now more elevated than the black ledge." Thus, in *only six years* the lower pit — nearly four hundred feet deep in June of 1840 — had been almost or quite obliterated. It is reasonable to conclude, therefore, that in 1844 two thirds of the original depth had been lost; and hence that when those great canals existed alongside of the black ledge, the lower pit was less than one hundred and forty feet deep, *except along the wide canals.* The next record gives the key to the mystery about the canals.

In the course of the next month, July of 1846, Rev. Chester S. Lyman (afterward Professor of Mechanics and Physics in the Sheffield Scientific School of Yale University), visited the crater, and found it in the condition reported by Mr. Coan. The account of his investigations, which he published in 1851,[2] states that "the whole interior of the pit had been filled up nearly to a level with the black ledge, and in some places fifty to one hundred feet above it." Moreover, Mr. Lyman proved that the change was not a change of level in the ledge, instead of the centre of the pit, by measuring a base and taking, with a quadrant, the altitude above it of the high western wall, making it six hundred and eighty feet, which agrees very nearly with the result of Wilkes's measurement.

Beyond all this, Mr. Lyman obtained full testimony as to *the way in which the rapid obliteration of the pit had gone forward*, and thereby reached an explanation of the so-called

[1] Coan, American Journal of Science, 1850, x. 361.

[2] American Journal of Science, 1851, 2d series, xii. 75. A letter from Mr. Lyman, dated Sandwich Islands, July, 1846, is referred to on page 193 of the author's "Expedition Geological Report;" but no facts respecting the crater are there cited except the one that some parts of the centre stand one hundred to one hundred and fifty feet above the black ledge; the author has no knowledge of what it contained beyond this.

canals. He found that while the bottom of the pit was almost level with the "black ledge," there was upon it, *along the inner margin of the ledge*, "a continuous ridge, more than a mile long, consisting of angular blocks of compact lava, resembling the debris at the foot of a range of trap or basalt," and that this ridge had a height "on its outer or eastern face often of fifty or one hundred feet [above the ledge], especially toward the south part, where it approached the Great Lake." Another remarkable feature of related import was the existence of a trough or "canal" between the ridge and the margin of the ledge, "several rods in width, and in some places forty or fifty feet in depth," — the same canal that had been reported in 1844. The ridge looked highest from the black ledge side, the ledge being lower than the interior plain. Following it southward, the slope on the interior side diminished in height, and finally ran out, while on the black ledge side the elevation increased until the slope became a precipice over one hundred feet high, which was so steep at "its southeastern limit that stones hurled from the hand cleared the foot of the bluff." The stones were "nearly three seconds in falling, which would give for the perpendicular elevation the amount just stated [or between one hundred and forty and one hundred and fifty feet]."

The "canal," as was learned from Mr. Coan, had been filling up, from a previous depth of two hundred feet, by flows of lava from the Great Lake. In July it was nearly filled, and in some parts obliterated.

After a survey of the facts as to the position and nature of the long ridge of lava-blocks, and a comparison with the condition in 1840, Mr. Lyman concluded that the ridge "once constituted a *talus*, or accumulation of debris," on the floor at the foot of the walls of the lower pit of 1840; that the floor with its margin of blocks had "been elevated, partly by upheaving forces from beneath, and partly by overflows from

the Great Lake and other active vents," until the talus overtopped "the precipice at the foot of which it was accumulated." He adds: "The phenomenon seems inexplicable on any other hypothesis than that of *the bodily upheaving of the inner floor of the crater.*" "When visited by the Exploring Expedition in 1840, the surface of the Great Lake was between three and four hundred feet below the black ledge, and measured only a thousand by fifteen hundred feet in diameter. Consequently in six years the lake had not only increased in size, but it had actually risen in height as much as it had been previously depressed by the out-draining of lavas in the eruption of 1840. This gradual rising of the solid embankment of the lake cotemporaneously with the lake itself, together with the filling up of the whole interior of the crater, is doubtless to be attributed to the combined effect of repeated overflowing together with the upheaving agency of subterranean forces."

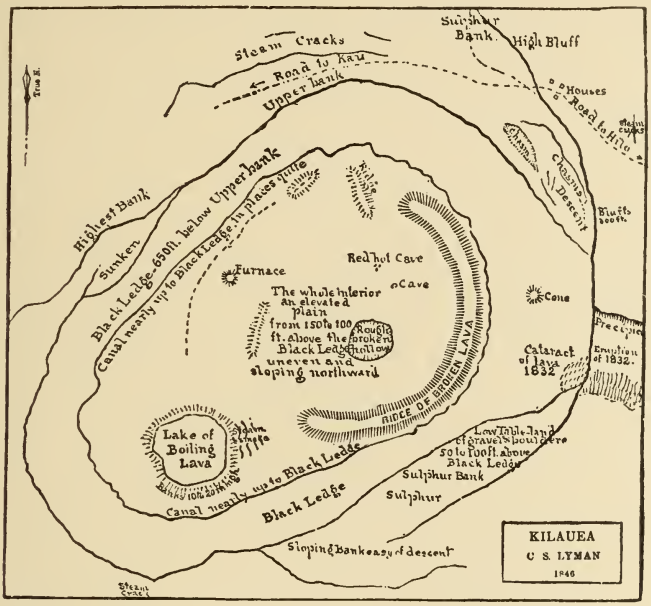
Mr. Lyman took a few compass-bearings in the crater, and some angles with a quadrant which he had constructed for the Kilauea visit, and left, with a friend on the Islands, a rapidly penned sketch of the crater showing the general condition of the interior. A reduced copy of the map with its lettering is here presented.[1] The position of the canal is stated on the map to be "nearly up to the black ledge, and in places quite," as in Coan's sketch; and it makes the whole circuit of the pit. The facts observed prove that the canal was a channel left between the black ledge and the talus-made ridge, and that it was, hence, an incident in the elevation.

The "Furnace," marked on the map, is described in his paper as oven-like, ten or twelve feet high, with walls a foot thick; as being inactive but showing within a glowing white heat early in July, but "in full blast" at his second visit in August, six weeks later. The large depression in the crater,

[1] American Journal of Science, 1887, xxxiv. 85, and 1888, xxxv. 24.

which contained steaming fissures and chasms, appeared to have been the site of a former lava-lake.

Kilauea, at the time of Mr. Lyman's visit, was only moderately active. The diameters of the Great Lake were twenty-four hundred and two thousand feet. Over its surface,



ten or fifteen feet below the brim, on which he stood, the lavas were in gentle ebullition. tossing up broken jets five to fifteen feet, and passing through frequent transitions between a crusted and a wholly molten state. It is evidence of relatively feeble activity that, standing on the brink, a handkerchief before the face was sufficient to shield it from the heat. In November of 1840 it was hardly possible to walk on the black ledge abreast of the lake, on account of the intense heat and light. The lavas had a general movement to the southwest. "A large stick of wood thrown on the lake, at a point where the ebullition produced a sort of eddy or rolling in of the lava, was immediately taken out of sight; but the next instant a more violent ebullition with a sudden out-

burst of flame and smoke told how, almost instantaneously, the stick had been transformed into charcoal."

In July, 1847, the Great Lake was boiling in much the same way as in 1846, with the liquid lavas still accessible, so that portions were taken out with canes.[1]

Dome of 1848. — Early in 1848 the lake was the most of the time unusually inactive, and became, as Mr. Coan states,[2] thickly encrusted over. The solid crust was soon after raised into a dome two or three hundred feet high, covering the whole lake. By August, the dome was almost high enough "to overtop the lower part of the outer wall of Kilauea and look out upon the surrounding country." The fires within were visible through fissures; and occasionally lavas were ejected in sluggish masses, or forcibly, from several apertures or orifices of the dome, which "rolled in heavy and irregular streams down the sides," spreading and cooling over the slopes or at the base. "The dome, as it now stands," Mr. Coan wrote, "has been formed by the compound action of upheaving forces from beneath, and of eruptions from the openings forming successive layers upon its external surface."

This is the first account of a dome over Halema'uma'u; and the description and explanation of it agree essentially with accounts of the most recent, for the external additions were but a small part of its mass. During the most part of the year 1848 "no fire was to be seen in Kilauea, even in the night."

Eruption, probably, of 1849. *Changes from* 1849 *to* 1855. — After the events just mentioned, no important change in the crater is mentioned before the spring of 1849, when in April and May there was a return to great activity, and start-

[1] Coan, American Journal of Science, 1851, xii. 80, letter of January, 1851. The author has a common iron spoon containing a spoonful of lava, dipped up by Mr. Coan at one of his visits. It is striking evidence of the extreme liquidity of the lava.

[2] Ibid., p. 81.

ling detonations were heard from the cones about the dome. The lavas were projected to a height of fifty to sixty feet from an opening in the top of the dome, and moreover the action became so violent elsewhere that "travellers feared to descend into any part of the crater." This state of unusual activity was such as foreboded an eruption. It suddenly ceased, and probably by a subterranean discharge. It left the central plateau and the dome undisturbed; but the lavas were gone from Halema'uma'u; only escaping vapors attested to fires beneath.

A time of unusual quiet, of "steaming stupefaction," followed, and continued on through 1850 and 1851.[1] Early in 1852 the orifice at the top of the dome was one hundred feet across, and boiling lavas were seen within.[2] By July this orifice had increased to two hundred feet; and it was still enlarging by falls of great masses into the abyss one hundred and fifty feet below, while steam and smoke were escaping from many holes in the sides of the dome, and lavas were ejected through a fissure dividing the west wall from top to bottom. Elsewhere the interior of Kilauea had little changed.[3] Mr. Coan predicted the speedy engulfment of the falling dome; but in the latter part of 1853 it was still standing, and probably was two miles in circuit, with a height of three to six hundred feet.[4]

The great central plateau, surrounded by what used to be called the "black ledge," continued rising, and in 1853 its surface, by Mr. Coan's estimate, was six hundred feet above the bottom of 1840, and in part two hundred feet above

[1] Coan, American Journal of Science, 1852, 2d series, xiii. 397.

[2] Ibid., 1852, xiv. 219, letter of March 5, 1852.

[3] Ibid., 1863, xv. 63, letter of July 31, 1852.

[4] Ibid., 1854, xviii. 96, letter of Jan. 30, 1854. "The Island World of the Pacific," by Rev. Henry T. Cheever (8vo, New York), appeared in 1851, with an account of a visit to Kilauea. But the descriptions give no information of value, and the two plates relating to Kilauea (pp. 287, 307) are from Wilkes, with large modifications in one and no acknowledgments; and with no statements that the view of the crater is an 1840 view, not 1850.

the ledge. His letter says: "Rising is going on . . . first by the lifting forces below, . . . second, by eruptive overflowings; the former is more uniform and general, the latter irregular and partial;" the former "in some places gradually, in others abruptly." Lyman's ridge of lava-blocks still existed, little changed.

The crater continued "unusually dull" through 1854. The central plateau had been long out of reach of the fires, and ferns and Ohelo bushes were growing on it.

Eruption, probably, of 1855. — In 1855 a change to unusual activity occurred, and it is thought probable that an eruption was the sequel.[1] The lavas underneath the dome commenced throwing up jets to a height of two hundred feet; vents were opened over the surface of the old black ledge; and thus in May and June the great central plateau had a girdle of fires nearly half a mile wide, in which Mr. Coan says he could count sixty lakes of "leaping lavas." There was one great lake at the foot of the northeast path down into the crater, and other "boiling caldrons" not far distant, so that access to the pit was cut off. The crater seemed to be ready for another eruption.

On July 6 Mr. Titus Munson Coan was at the crater, and found the lava-lake in the northeast quarter mostly crusted over, but in some places along its margin the lavas were in violent action, splashing and throwing up the fiery spray. Halema'uma'u was by estimate four hundred by two hundred and fifty feet in its diameters, and seventy-five feet deep to the lava. A grayish filmy crust of hardened lava covered it most of the time. But every four or five minutes, near the centre, the crust would grow thinner, split, and, rapidly parting, open to view a fiery surface ten to eighteen feet across, in which the lava, after heaving up and down for

[1] Coan, American Journal of Science, 1856, xxi. 100, letter of July 18, 1855, and p. 139, letter of Oct. 15, 1855.

a few seconds, burst into a fountain of twenty to thirty feet; and then, falling back, the spot became quiet and the red surface quickly took on its gray filmy covering. Near by, another similar fountain in a few seconds would start into action and go through the same changes. In great cavern-like openings under the northeast wall, there were furious surgings and outthrows of the lavas. The wall of Halema'uma'u was tufted with Pele's hair, which was perpetually being formed from the lava projected into the air. Two islands stood unmelted in the northwest part of the lake.

On October 9 the crater was still active, but less intensely so. The dome over Halema'uma'u had fallen in.

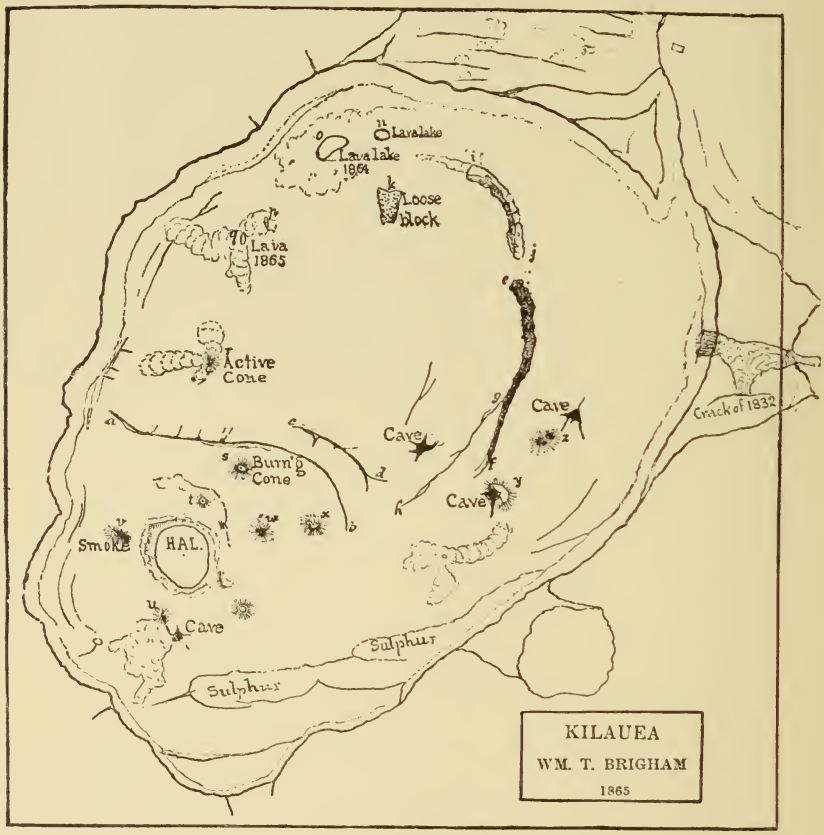
Mr. Coan's report of March, 1856, mentions several visits to the *summit eruption then in progress*, but nothing about Kilauea until October of that year, when he speaks of the crater[1] as declining in activity for the year past, since the summit eruption began; "getting more and more profoundly asleep; . . . only a little sluggish lava in the great pit of Halema'uma'u, but much escaping vapor." A subterranean discharge took place probably in October, 1855.

1855 *to* 1864. — In June of 1857 Kilauea was still quiet.[2] The lavas of the Great Lake were but five hundred feet across, and one hundred feet below the edge. The alternations from the crusted to the completely molten state *took about three minutes.*

Through the following year, as during the two preceding, there was little change. In August, 1858, the Great Lake, some five hundred feet in diameter, "boiled and sputtered lazily at the centre of a deep basin which occupied the locality of the old dome. The action alternated between general refrigeration and a breaking up of the whole surface with intense ebullition."[3]

[1] Coan, American Journal of Science, 1857, xxiii. 435, letter of Oct. 22, 1856.
[2] Ibid., 1858, xxv. 136, letter of Sept. 1, 1857.
[3] Ibid., 1859, xxvii. 411, letter of Feb. 3, 1859.

In 1862 the condition was but little different. Halema'uma'u had a lake at centre "about six hundred feet in diameter." Within the basin, a fourth of a mile from the border of the lake at its centre, there was a large mound of lava (a blow-hole product), with pinnacles and turrets, somewhat cathedral-like.[1] In the summer of 1863[2] activity had not much increased; at *intervals of a few seconds to half a minute*, a large fountain broke forth at the middle of the lake, throwing up a rounded crest of lava ten to twelve feet,



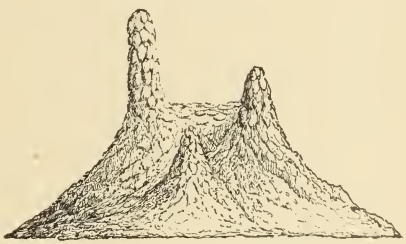
and smaller portions to a height of twenty to thirty feet, while elsewhere there was a filmy crust through which

[1] Coan, American Journal of Science, 1863, xxxv. 296, letter of Nov. 13, 1862.
[2] O. H. Gulick, Ibid., 1864, xxxvii. 416, letter of July 25, 1863.

small stones thrown in sank; and then again there was ebullition at various points in the lake, — facts showing that the action was still far from brilliant.

In October, 1863, Mr. Coan reported new activity in the Great Lake, and through the whole circumference of the crater, with outflows that covered the old black ledge with fresh lavas. But the central plateau, "a distinct table-land," probably five to six hundred feet above the bottom of 1840, remained unchanged.[1]

1864 – 1866. *Observations and Map of* Mr. William T. Brigham. — In 1864 Mr. Brigham visited Hawaii, and began the observations on its volcanoes reported in his memoir. The accompanying reduced copy of the map made by him from his survey in 1865, deserves special attention. The map confirms the statements, made from 1846 onward, as to the obliteration of the lower pit. It shows the southwestern sulphur banks, but much diminished in extent since 1840 from lava-overflows. Halema'uma'u has apparently its old position, or is very near it. There are also, on the map, other lakes of small size; cones, two or three of which were driblet-cones, of blow-hole origin, and one, *e*, named the Cathedral, from its half-dozen turrets (here represented from his figure), is the same that was seen in 1862 by Mr. Coan.



The Cathedral: Driblet-cone, 1864.

The map shows also two long pieces (*e f*, *i j*) of Lyman's ridge of loose blocks of "compact broken lava, . . . concentric," as Mr. Brigham reports, "with the main wall of Kilauea, . . . marking the limits of Dana's black ledge [that is, the black ledge of 1840]; . . . composed of fragments

[1] Coan, American Journal of Science, 1864, xxxvii. 415, letter of Oct. 6, 1863.

of all sizes and shapes, very solid and heavy, and full of small grains of olivine."

A recent letter from Mr. Brigham informs the writer that the ridge *i j* (which is not particularly mentioned in the report) had the same constitution as *e f*, but consisted of larger blocks.

Other interesting features, indicated on the map, are (1) a wall, *a b*, — fault-wall, — enclosing an amphitheatre, that of the Halema'uma'u region, perhaps a result of the undermining occasioned by a discharge of the lavas of the lake at some unrecorded time; (2) just north of this, a deep fissure, *c d*, concentric with the wall *a b*; and (3) warm or hot steaming caverns in the floor of the crater, some of which were hung with gray-black, often tubular, stalactites.[1]

The text states that in 1864 the "black ledge" region was fifty feet below the level of the interior plain of the crater, and that the difference in level was the same in May, 1866, although both had been much raised, — "at least a hundred feet," — the former by overflows and the latter without overflows.

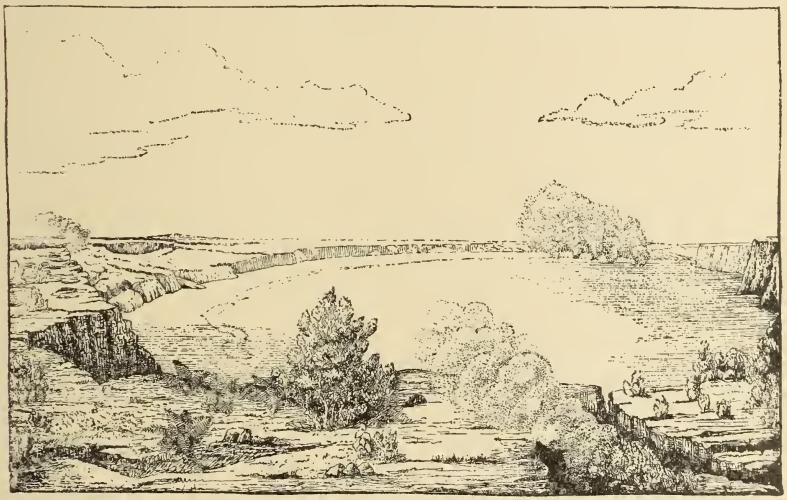
Mr. Brigham does not allude to Mr. Lyman's explanation of the long ridge of lava-blocks. He remarks as follows on page 421, after stating the constitution of the ridge, as already cited: "This wall, which is concentric with the main wall of Kilauea, is said to rise and fall and sometimes disappear, — which seems to be a fact, although no one has ever seen it in motion. It is [made up of] the fragments broken from the edge of the crater by an eruption, and floated out to its [the wall's] present position." Again (p. 415): "From a manuscript map prepared by Mr. Lyman, I find the ridge occupied the same position as at present." Again, in his account of the crater in May, 1866 (p. 427): "The ledge of broken lava which swept around the eastern end of the

[1] The stalactites are described on a following page. The temperature of the caves was usually 80° – 95° F.

crater, marking the limits of Dana's black ledge, is nearly covered with the successive overflows."

The Great Lake had a diameter of about eight hundred feet in 1864, and of one thousand in August, 1865. Its lavas in 1864 were fifty feet below the edge, and extended into caverns beneath it. The action was mostly feeble: "occasionally a crack opened, and violent ebullition commenced at several points;" again it was liquid, but soon passed to the viscid condition; again "boiling violently, and dashing against the sides, throwing the red-hot spray high over the banks." There were two small islands in the lake in 1864; but in August, 1865, they had disappeared, and the lavas were then only thirty feet below the edge.

The following view is copied from a photograph of a painting by Mr. Perry, a California artist, which I received from Mr. W. T. Brigham in March, 1865: —



Kilauea in 1864.

Its close correctness is sustained by comparison of the outlines of Kilauea with those of Drayton's sketch. It has great interest because it gives the position and general appearance of Lyman's ridge of lava-blocks, corresponding well with the

same in Mr. Brigham's map. The point from which the view was taken was apparently a little to the east of that selected by Drayton, and hence the differences in the western wall and some other points.

The existence of flames over the large boiling lake is attested to by Mr. Brigham, who says, on page 423, speaking of a midnight view, that "they burst from the surface, and were in tongues or wide sheets a foot long and of a bluish green color, quite distinct from the lava even where white-hot. They played over the whole surface at intervals, and I thought they were more frequent after one of the periodical risings of the surface."

In May, June, and July of 1866 [1] there was a great increase of activity in Kilauea, beginning just after the cessation of the summit eruption. In May new lakes of fire and new cones were opened along a curving line extending from the Great Lake northwest to north and northeast, thus again covering the "black ledge" portion of the crater, flooding the surface with lavas for a distance of two miles, and with a breadth in some places of half a mile; and for days the flood of lavas closed the usual place of entrance to the crater. Large blocks were shaken down from the walls of Kilauea; and Mr. Brigham observes that these blocks were soon removed by the intensely active flood at their base, "showing how pit craters may be enlarged horizontally." In August the force of the eruption seemed to be spent; but no subterranean outflow is known to have occurred. During all the activity the central plateau of the crater remained undisturbed.

Eruption of 1868. — In 1868 a great outbreak and down-plunge took place in Kilauea, almost simultaneously

[1] Coan, American Journal of Science, 1867, 2d series, xliii. 264; Brigham's Memoir, p. 427.

with an eruption from the summit-crater of Mount Loa.[1] It was preceded by a succession of heavy earthquakes, — two thousand or more, according to reports, — commencing on the 27th of March and culminating on Thursday, the 2d of April, when a shock occurred of terrific violence, which was destructive through the districts of Hilo, Puna, and Kau, northeast, east, south, and southwest of Mount Loa, and was felt far west of the limits of Hawaii. With the occurrence of this great shock, fissures were opened from the south end of Kilauea southwestward through Kapapala, a distance of thirteen miles, and bending thence southward toward the coast. The position of this line of fissures is shown on the large map of Hawaii published by the Government Survey in 1887 (frontispiece); it followed the course of the earlier fissures of 1823. Some lavas were ejected from the openings in Kapapala, which were probably lavas from Kilauea. Simultaneously with the violent shock, a decline began in the fires of Kilauea.[2] By night of that same Thursday, the liquid lavas had disappeared from all cones and were confined to the lakes; by Saturday night, all the lakes were emptied except the Great Lake; finally, by Sunday night, the 5th, the Great Lake had lost its lavas, and all was darkness and quiet. Where the lava went to is unknown.

A down-plunge of the central part of the floor of the crater took place at the same time, so that again a lower pit existed, as in 1840. Mr. Coan, in describing it, says that the plateau "sagged down" three hundred feet; and another

[1] Dr. William Hillebrand, American Journal of Science, 1868, 2d series, xlvi. p. 115; Coan, Ibid., p. 106; F. S. Lyman, Ibid., p. 109; H. M. Whitney, Ibid., p. 112; Coan, Ibid., 1869, xlvii. 89, letter of Sept. 1, 1868, with a map of southern Hawaii on page 90. Also the same letters in a paper by Mr. William T. Brigham, in the Memoirs of the Boston Society of Natural History, i. 564, with a map on page 572. The map was made by Mr. Brigham from his survey in 1865 and the descriptions of the 1868 eruption.

[2] A letter from Rev. E. P. Baker, of April 5, 1888, states, on the authority of Mr. Richardson, that the subsiding of the lavas began immediately after the earthquake of April 2d.

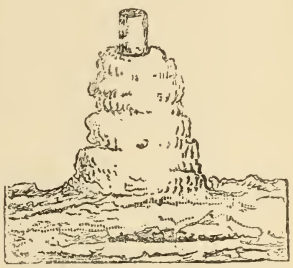
writer, after a visit to the pit, gives the same depth, and remarks "just as ice falls when the water is drawn from beneath." The great sunken area had not vertical walls, like that of 1840, but sloping sides, as the term "sagged" implies; the slope generally thirty to sixty degrees, but at a much less angle on the side toward Halema'uma'u. There was again a black ledge, and it was nearly of its old width, but at a somewhat higher level owing to the overflows. The emptied Great Lake, three thousand feet in diameter at the top, fifteen hundred feet below, and five hundred feet deep, was literally empty; it showed no light at bottom by day and not much at night. The discharge of lava may have been as great as in 1840, although the lower pit made by the undermining had less extent.

Mr. Nordhoff, in his "Northern California, Oregon, and the Sandwich Islands,"[1] page 45, says, speaking of this outbreak: "Suddenly, one day, the greater part of the lava-floor sank down, or fell down, a depth of about five hundred feet, to the level where we now walked. The wonderful tale was plain to us [March 3, 1873] as we examined the details on the spot. It was as though a top-heavy and dried-out pie-crust had fallen in at the middle, leaving a part of the circumference bent down but clinging at the outside of the dish." Mr. Nordhoff's statement as to the depth of the lower pit was evidently quoted, and is not independent testimony; but his comparison suggested by the sight of the place, sufficiently intelligible to an American, attests to the reality of the subsidence.

Another remarkable fact is stated: that just before the earthquake of the 2d of April, "the lavas of Kilauea burst up vertically and spread over the old deposit of 1832." A fissure opened in the depressed area between Kilauea and Kilauea-iki, which extended on for nearly a hundred yards.

[1] Nordhoff, Northern California, etc., New York and also London, 1874.

The lava of the outflow was still lustrous, and mostly free from vegetation in the summer of 1887, while that of 1832 was much weathered and mostly under dense vegetation. As has happened in most Hawaiian eruptions, trees were enveloped by the lava-flood. Half-charred trunks were standing, in 1887, with a rough cylindrical encasement of lava about the stumps, projecting from two to two and a half feet or more above the level of the solidified stream, as in the figure, showing that when the lava reached the trees on its way down the slope, it had greater height of surface than afterward when the flow had passed by and its final level was attained.



On Tuesday, April 7th, five days after the beginning of the Kilauea discharge, the lavas were ejected in great volume at Kahuku in southwestern Hawaii, and flowed to the sea. It was at first a question whether a part of the Kahuku flow might not have come from Kilauea. But the extinction of the summit fires occurred at the same time, and the Kahuku discharge was in a line with fissures leading toward it from the summit, so that Mokuaweoweo is believed to have been their only source. The conduit of the Kilauea lavas was probably ruptured at the time of the great shock, and hence the discharge.

The curving of the Kilauea fissures from Kapapala toward the coast seems to point to a submarine discharge off that part of the island.

4. Kilauea from 1868 to 1890.

This period of eighteen years passed without another down-plunge of the floor of the pit. The gradual filling of the new-made lower pit, and the ultimate merging of

all slopes at the crater's bottom into those leading off in all directions from Halema'uma'u, are the chief events of the period. Mr. Lydgate's map, on the following page, shows an intermediate stage in the progress.

Changes from 1868 *to* 1879. — After the discharge and consequent exhaustion of 1868, Kilauea was slow in its return to activity. In July of 1869 Mr. Coan found the crater quiet, and the basin of the Great Lake so nearly cooled that he went down into it and measured across its bottom four hundred feet below the rim; he found it "five sixths of a mile" wide, and at top more than a mile from the north to the south side. Down deep fissures within the emptied basin he could see the lavas, fifty to one hundred feet below, still in ebullition.[1]

Two years later,[2] in 1871, the Great Lake was full, and successive overflowings had covered deeply the southern end of the crater and sent streams two miles northward, filling the central pit to a depth of fifty feet. In August of 1871 Halema'uma'u was again a deep cavity, hot and full of dense vapors,[3] but before August of 1872 it was full with lavas and often overflowing into the great basin of 1868.

On March 3, 1873, Halema'uma'u, according to Mr. Nordhoff,[4] was divided between two lakes, their shorter diameter about five hundred feet; "the two were separated by a low-lying ledge or peninsula of lava; each was red, molten, fiery" within. From the "north bank" the depth of the pit or basin down to the lavas was seen to be about eighty feet, and "the two large lakes appeared to be each nearly circular."

In January, 1874, says another observer, the lower pit was still much below the ledge. The surface of the Great Lake

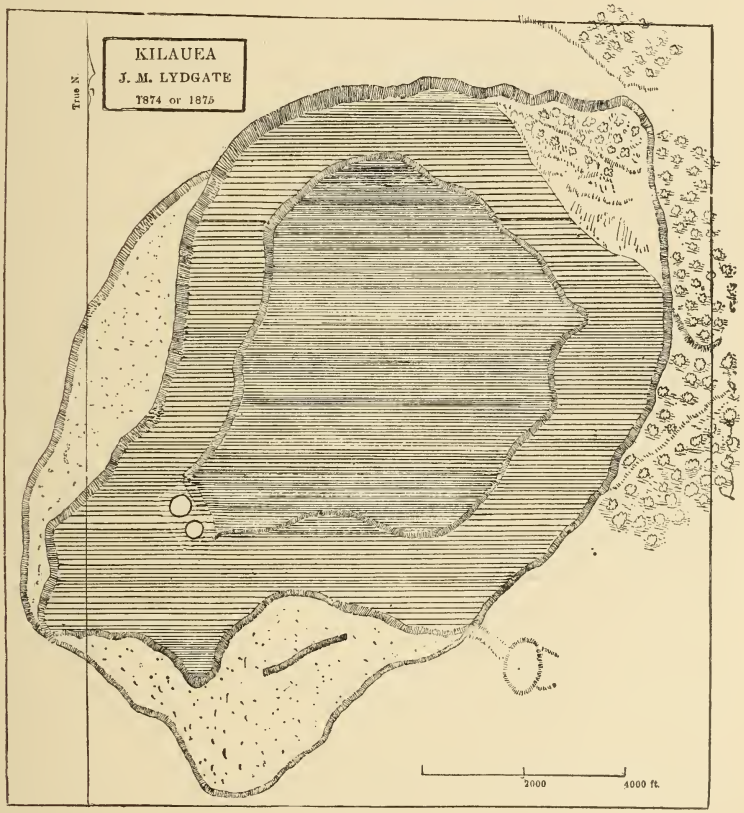
[1] Coan, American Journal of Science, 1879, 3d series, ii. 454, letter of August 30, 1871, and xviii. 227.

[2] Ibid., 1871, ii. 454.

[3] Ibid., 1872, iv. 407, letter of August 27, 1872.

[4] Northern California, Oregon, and the Sandwich Islands, 1874.

was thirty-five to forty feet below the edge of the basin, and "possibly" five hundred feet by nearly half a mile in its diameters, but divided almost in two by a low bank of rock. Four months later, on the 4th of June, the cone about the Great Lake had risen much, and the lake was divided through into two oblong lakes, a northern and southern, in the direction of the longer diameter; it lay below precipitous and partly overhanging walls that were eighty feet high. The action was less intense than in January. There were active cones near by. One hundred yards from the lake, one typical blowing-cone "of beehive shape," twelve feet high,



about forty feet deep within, and having walls two feet thick, was throwing up jets and clots of lava through holes in its

sides, "with a deafening or rather stunning roar" and subterranean rumblings and detonations.[1]

In June of 1874 a map of the crater was made by Mr. J. M. Lydgate.[2] It has great interest, since it shows the central depression or pit of 1868 still well defined, and also the subdivision of Halema'uma'u, above alluded to.

Early in October of 1874, according to Mr. Coan, "the great central depression of 1868 had been filled up by deposits about two hundred feet," and the region around the Great South Lake had become a truncated elevation nearly as high as the southern brim of the crater.[3]

In December, 1874, Mr. J. W. Nichols, of the British Transit of Venus Expedition of 1874, was at Kilauea. A brief note by him contains the following facts:[4] A low cone around Halema'uma'u about seventy feet high; diameters of the basin one-half and one-quarter of a mile; within it, four lava-lakes, the largest two hundred yards in length; in the largest, seven or eight fountains of white-hot lava playing to a height of thirty to forty feet, one of them sometimes stopping, and then commencing in another part of the lake; the fountains in every case playing around the edges of the lake; lava of largest lake about fifty feet below the brim; one of the smaller lakes brimful of lava when in the others the lava-surface was thirty or forty feet below the brim; in one, a single fountain bursting from a cavern in its side. The summit crater is stated to have been in action about a month before the visit.

During the Year 1878 *and the early Part of* 1879. — In January, 1878, Mr. C. J. Lyons, of the Government Survey

[1] Isabella L. Bird, The Hawaiian Archipelago, London, 1875, pp. 55, 253.

[2] For this tracing I am indebted to the Surveyor-General, Mr. Alexander, the original being in the archives of the office of the Hawaiian Survey. The precise date was not given on the tracing; but by letter from Mr. Lydgate, the date is now known to be as given above.

[3] Coan, American Journal of Science, 1874, 3d series, viii., letter of Oct. 6, 1874.

[4] Proceedings of the Edinburgh Royal Society for 1875–1876, pp. 113–117.

Office, obtained, by means of a theodolite, three hundred and twenty-five feet as the level of the lavas of Halema'uma'u below the datum mark at the Volcano House.

The following facts, bearing on the condition of the crater in 1878 and the early part of 1879, were copied by the author in 1887 from the hotel-book of the volcano : —

July 20, 1878. "Halema'uma'u in a most active state." — M. P. Robinson.

September 20. "Very active." — J. Mott Smith.

November 24. "Very active ; lava within a foot of top of bank."

Jan. 8, 1879. "South Lake with lava fifty feet below the rim and boiling like water." — Wm. Gardner.

March 19. "Large and bright lake."

April 15. "Light wonderful."

Eruption of 1879. — The facts from the Volcano House hotel-book and the testimony of Mr. Coan and others, were evidence that Kilauea was ready for another eruption. The threatened eruption took place between the 18th and 21st of April, 1879, — the 21st, according to information reported by Miss C. F. Gordon Cummings, who was at the crater in the autumn of that year.[1] Mr. Coan reported, in a letter of June 20, that the Great Lake, which had been running over, and whose rim had been raised till nearly as high as the outer edge of Kilauea, was suddenly emptied by a subterranean outlet and subsided several hundred feet, leaving nothing but "a smoking basin." [2]

But the hotel-book records fix the date : —

April 21, 1879. "Bottom dropped out of crater." — Wm. H. Lentz, of Honolulu.

April 23. "Found the —— thing extinct." — G. Grœper.

April 28. "Almost extinct ; some vapors." — Rev. A. O. Forbes, of Honolulu.

April 29. "No fire at all. . . . Lake quite empty." — J. Day.

[1] Fire Fountains of the Kingdom of Hawaii, 2 vols. 8vo, London, 1883.

[2] Coan, American Journal of Science, 1879, xviii. 227, letter of June 20, 1879.

After some days, in which there was no evidence of fires except that from escaping vapors and steam, the lava reappeared. The hotel-book of the Volcano House contains the following proof that in June the great basin had recovered activity : —

June 24, 1879. "Throwing up jets of lava ; both lakes active ; looks like a fountain of fire from the veranda of the Volcano House." — Wm. H. Lentz.

July 2. "All traces of two lakes of July, 1878, obliterated, and instead an enormous single lake, which was quite active ; . . . lava thrown up fifty feet." — Wm. Tregloan, of Honolulu.

By May, 1880,[1] Halema'uma'u had become a boiling and overflowing lake, pouring its streams into the great central basin of the crater.

In July of 1880 Mr. William T. Brigham was again at the crater.[2] The floor was found to rise into a "tolerably regular dome" which was "surmounted by four lakes of an average diameter of a thousand feet." The latest of the four, the southeastern, commenced to form May 15 of that year, and its bank was in part nearly on a level with the lavas ; but the others had stratified walls, as is stated and figured, which were in places one hundred feet or more in height, and from their front there were frequent avalanches, owing to the undermining action of the active lavas beneath. These lavas were seen here and there to be white hot in the night view. In the darkness "a large volume of gas" was observed escaping from a cluster of blow-holes in the vicinity of the lakes, "which burned with a bluish-green flame," differing in its continuance from the flames seen before by Mr. Brigham, which "seldom lasted longer than a few moments."

The four lakes replaced old Halema'uma'u. By sighting from two of his monuments left from the 1865 survey, Mr.

[1] Coan, American Journal of Science, 1880, xx. 72, letter dated May 3–6, 1880.
[2] Brigham, Ibid., 1887, xxxiv. 19.

Brigham obtained evidence that the area of the old lake lay "in the midst of the present four lakes" instead of corresponding with either of them. This would make the summit of the dome to be in the Halema'uma'u part of the crater, or its southern portion, as in 1886, the dome having in fact "a very eccentric apex."

In 1882 Captain Dutton made his examination of Kilauea. He states that after reaching the floor of the crater he walked over the uneven surface for about a mile and three-quarters, and then came to a rapidly ascending slope, rising about one hundred feet; and from the top of it looked down on "New Lake," about four hundred and eighty feet long and three hundred feet in width, lying between walls fifteen to twenty feet high, situated to the northwest of Halema'uma'u. This lake first appeared, he states, in May, 1881.[1]

New Lake was much of the time crusted over, showing fires only at the edges. Break-ups, making cracks over the whole surface, and followed by an engulfing of the numberless fragments until "the whole was one glowing mass of lava," occurred at intervals of forty minutes to two and a quarter hours; but they were of short duration, and the lavas in the mean time were "quite black and still." Now and then a fountain broke out in the middle of the lake and boiled feebly for a few minutes; then it became quiet, "but only to renew the operation at some other point." The larger and more active lake, Halema'uma'u, half a mile off, was surrounded by a cone of loose lava-fragments, the lavas a hundred feet below the top. The lake was to a considerable extent crusted over; but there were boiling fountains of liquid lava five to ten feet high (by estimate) in play, changing their positions from one part of the lake to another, one dying out as another started up. Two masses of solid

[1] Coan, American Journal of Science, 1883, xxv. 220, letter of Feb. 8, 1883; and United States Geological Report, loc. cit.

lava were seen in the New Lake, looking as if formed in it, which in the course of several days shifted their positions, showing that they were floating islands.

Eruption of March, 1886. — The above-described conditions continued, though with great variations, until March of 1886. On the 6th of that month both Halema'uma'u and the "New Lake" (see Plate III.), the latter five years old, were unusually full and active, and mingled their floods in overflows. The next morning, March 7, between two and three o'clock, the lavas disappeared and left both basins empty, — first the shallower New Lake, and then the Great Lake. The cone around the latter, then two hundred feet in height above the boiling surface, fell into the emptied basin, and for days the down-plunge of the walls continued.

The eruption was thus a simple running off somewhere of the lavas, and a down-plunge of the undermined region was a consequence. There had been a great increase of activity within and about Halema'uma'u, which at last had extended in a subterranean way to the northern borders of the crater. The fissures of the solfatara region on the northern border of Kilauea, west of the Volcano House, sent up hotter air and vapors than usual, foreboding some change. The bathing-house of the hotel, fitted up for vapor baths, is in this depressed region over one of the fissures. The proprietor of the house, Mr. J. H. Maby, found on the afternoon of the 6th of March (Saturday), when wishing to take a bath, the vapors at repeated visits too hot for it, and finally gave it up. At half-past nine of that evening a slight earthquake was felt, and at a quarter of ten three others, which made "thud-like sounds," or "like the fall of a meal-bag on the floor;" at ten the light over Halema'uma'u, before very brilliant, suddenly disappeared, — the *eruption* had taken place.

Through Sunday morning the escape of vapors from the

Sulphur Banks
Sandy Plain
Steam Cracks
Kenakakoa
VOLCANO HOUSE
North Base
Kamohoali
Gravel
Kilauea
Waldron's Ledge
Woods
KILAUEA IKI
Ae Patch
Land and Gravel
Pali
Lava Bed
Block Sand
HALEMAUMAU
Control Rock
Mille Beggar
NEW LAKE
Pumice
Gravel
Pali
KEANAKAKOI
Gravel and Large Boulders
Kapuu
Pali Pahaku
Steam Cracks
Pumice
Holoholoaloa
Old Kau Road
HAWAIIAN GOVERNMENT SURVEY
W D Alexander Surveyor General
THE CRATER OF
KILAUEA,
HAWAII.
Scale 1: 6000
Surveyed in Sept - Oct. 1886, by
Frank S. Dodge.
Outlines of Halemaumau and New Lake
and a portion of the Triangulation by
J. S. Emerson
Map by Frank S Dodge.
Nov '86.
All elevations are referred to Volcano House Verandah floor which is 4040 feet above Mean Tide.

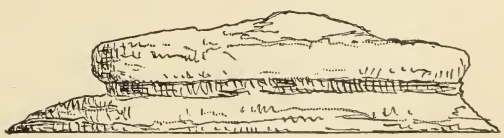
fissures of the solfatara region near the Volcano House went on, but it ceased entirely on Tuesday, and the stoppage continued through Wednesday and Thursday. Afterward the discharge was gradually resumed.

Forty-one earthquakes are reported as having occurred during the night, but none strong enough to shake down furniture in the Volcano House, or crockery from shelves. The shocks have been attributed to the down-plungings of the walls of Halema'uma'u consequent on the discharge of the lavas; but the intervening distance, twelve thousand feet, is too great for such an effect from the feeble vibrations so caused. Moreover, there was a cause nearer by; for deep fissures were opened for a mile along the road that goes east from the Volcano House, commencing at a point not far from the house. The fissures were still steaming in August, 1887.

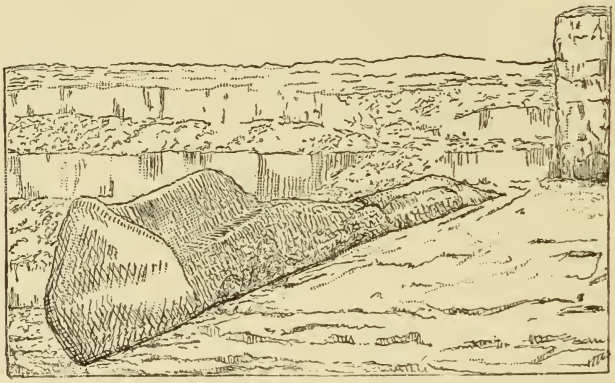
The forty-one feeble earthquakes felt on the margin of the crater at the Volcano House disturbed no other part of the island, and they were the only semblance of violence at the time of the eruption. There was a down-plunge as in other eruptions, but it was all confined within the area which included Halema'uma'u and the associated New Lake.

Where the lavas of the lake went, is the old question again unanswered. Perhaps into some cavernous subterranean region, or perhaps into the sea by an opened fissure.

The New Lake had had since 1882 its "floating island." A photograph gives the following view of it in its earlier condition. It looks as if it had been a part of a solidified lava-stream which had been floated off from the sides of the lake or had been buoyed up to the surface from the bottom. Its lavas were not much vesiculated;



but the air-cells were evidently sufficient to enable it to float. It changed much in form from 1882 to 1886, as photographs indicate, probably from encroachments on it by the fusion of its sides, and also from the additions to it through the throws of liquid lavas over it. At the eruption it was left stranded at the bottom of the emptied



"Floating Island" of New Lake, Stranded.

lake-basin. This view, exhibiting its condition in August, 1887, is from a photograph. It is not known how much of it was beneath the surface of the lava; but the reader may perhaps satisfy himself on this point.

After the Eruption of March, 1886, *during the rest of the Year.* — The reports of Mr. J. S. Emerson, Prof. S. S. Van Slyke, and Mr. Dodge give details as to the conditions of the crater within the first eight months after the eruption.[1] The first and last were made to the Surveyor-General, Professor Alexander.

Mr. Emerson was at the crater seventeen days after the event on March 24, and remained till April 14. He says that in this interval "no molten lava was anywhere visible in the entire crater. At certain points of easy access a stick could be lighted by thrusting it down a crack so as to bring

[1] American Journal of Science, 1877, xxxiii. 87, 95, 98.

it in contact with the red-hot rocks beneath; but in general there was scarcely a place from which I was prevented access on account of the heat." The total depth below the datum at the Volcano House to the bottom of the basin of Hale-ma'uma'u was found to be nine hundred feet, and below the rim of the basin about five hundred and ninety feet.

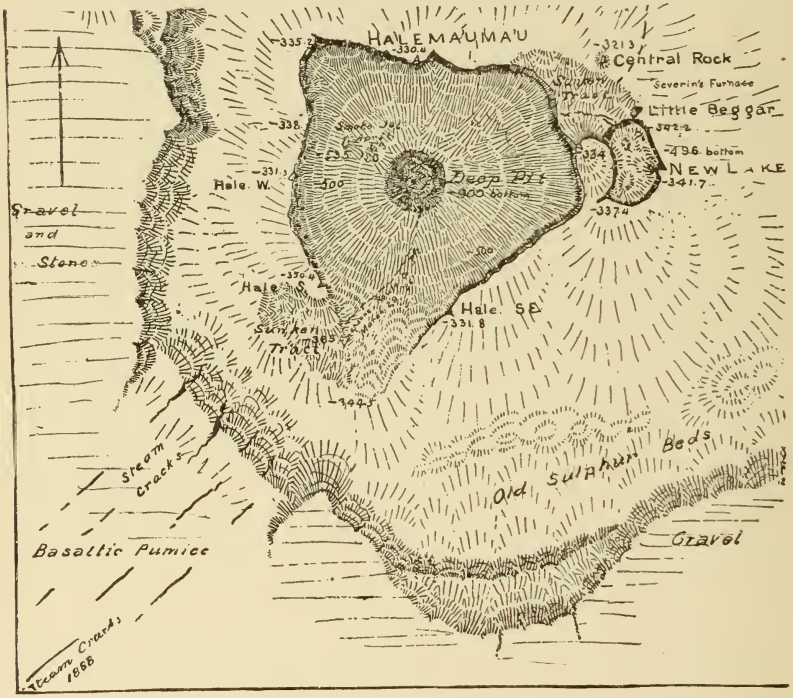
On the 29th of March he descended into the pit; only Rev. E. P. Baker had preceded him. The sides were covered, not by small fragments of lava or gravel or scoria, but by great irregular slabs of the smooth-surfaced lava (pahoehoe), six to eight or more feet long, five or six feet wide, and about a foot thick, and mostly so placed as to slope downward, though many were tilted in all directions; they looked as if ready to slip to the bottom. But at a depth of about three hundred and twenty-five feet, or two hundred and seventy-five feet from the bottom, where the diameter was about six hundred feet, this rough flooring of pahoehoe slabs came abruptly to an end, and a nearly circular pit began, which had the form nearly of an inverted cone. A view of the condition is shown in the accompanying map of the Hale-ma'uma'u region by Mr. Emerson. The lower basin had an even, lustreless surface, free from large blocks and notable fissures, and consisted chiefly of coarse gravel or fragments of lava, but at bottom of smooth black pahoehoe, free from debris, and of somewhat triangular shape, with sides of twenty-five feet. From a small fissure issued a faintly bluish vapor.

In the upper part of the basin, on the northwest side, about 364 feet above the bottom and 225 feet below the top, there was a continuous jet of steam from an oval aperture of five to ten feet. This continued to increase, and on the 12th of April deposits of sulphur were formed about it.

Within the basins of New Lake and Little Beggar there were hillocks of smooth-fissured lava, without debris. The huge hulk of the "Floating Island" lay as in the

sketch, and on measurement proved to be sixty feet high and fully a hundred feet in length. The walls of the emptied basin of New Lake were for the most part nearly vertical, and were everywhere covered with a black, vitreous enamel.

The hottest part of the Halema'uma'u depression was on the southwest side; and in the same direction, to the south-



HALEMA'UMA'U in April, 1886.

west of Kilauea, where there are old fissures of 1868 which are still steaming, there were other fissures which appeared to be of recent origin.

Professor Van Slyke reached the crater on the 19th of July, — three months after Mr. Emerson left it. He reported great changes in Halema'uma'u; for liquid lava had again appeared, and besides, the central region of the great basin had been "upheaved." The upheaving will be understood from Plate III. Within the basin of Halema'uma'u,

North End of the Halema'uma'u Basin and of the Debris-cone within it.
(From a photograph, taken looking westward, January, 1887.)

from four hundred to a thousand feet from its precipitous north wall, there was a steep mound or cone of loose blocks of solid lava about a hundred and fifty feet high, dropping to about thirty feet on the northwest side. It occupied the central part of the basin, and consequently had a deep and wide depression around it. Already a lava-lake of about five acres existed within this depression; and besides this Professor Van Slyke saw active fires under cover beneath the cone. He states: —

"Ascending the cone part way, I came to the edge of a deep hole or well, of rather irregular outline, four-sided, perhaps thirty or forty feet wide, and from sixty to seventy-five feet long, and not less than a hundred feet deep. The mouth was surrounded by masses of loose rocks, rendering approach to the edge impossible or very dangerous, except at one point; from this point I could see the bottom of the well, and that it was covered with hardened fresh pahoehoe. At one side the liquid lava could be seen as it was puffed out of a small hole every few seconds and thrown up a few feet. The puffing noise accompanying the ejection of the lava was quite like that of a railway locomotive, though louder. The aperture through which the lava was thrown out might have been three feet long and two feet wide. Immediately beneath the point where I was standing there seemed to be a constant and tremendous commotion, attended by a peculiar swashing noise, but I could not lean sufficiently far over with safety to see anything. Fumes of sulphur dioxide were coming up in abundance, but being on the windward side I was not greatly annoyed by them."

From the southeastern side of Halema'uma'u he went again up the sides of the cone: —

"This led to a second well or deep hole, where molten lava was visible. This well was nearly round, with a diameter of perhaps twenty or thirty feet, and a depth of about a hundred feet. At one point the edge could be safely approached; but as it was on the leeward side the fumes of sulphur dioxide could be endured only for a few seconds at a time. Like the other well, the sides were perpendicular. At the bottom was a cone having an opening at the top perhaps ten feet across; and inside liquid lava was boiling with intense violence, every few seconds throwing up a jet of lava, the

spray of which came to the mouth of the well almost into my face. The drops of lava thrown to the mouth of the well had cooled enough to become hardened and black when they reached the level on which I was standing. This place was quite noisy, the noise resembling that of violently swashing waters."

Besides the deep holes just described, there was, as has been mentioned, a "lake" of liquid lava. It was situated immediately beneath the west wall of Halema'uma'u at the bottom of the wide depression between this wall and the cone-like hill of loose rocks. It extended to the "Smoke Jet," a distance of four hundred feet approximately. It was possible to get down to the edge of the lake, but very hazardous. On the occasion of his first visit, in a view from the north side, the entire surface was hardened and black, the only sign of volcanic activity being little steam-jets here and there. After about an hour some liquid lava burst through the black crust and flowed away. Such little outbursts were followed by others larger. Two days later there was much puffing and swashing and some boiling lava.

Mr. Dodge was at Kilauea, on survey duty, during the last week of the following September and the first of October. The map (Plate III.) is the result of his work and of the previous survey of Mr. Emerson. It brings out strongly the fact that previous to the eruption of 1886 the floor of the crater had been flooded again and again by the streams from Halema'uma'u, until the whole was covered throughout with the new lavas. The surface sloped away from the lake in all directions, as it had done since 1880, and this was true even to the farthest northeastern walls. These universal fiery floods, making the existing floor, took place during 1885, or the year preceding the eruption. They left the depth at the foot of the northeast wall 482 feet below the Volcano House; over the centre of the floor 350 to 375 feet, and at the summit of the eccentric cone of the crater, about Halema'uma'u, 320 to 340 feet. There was consequently, as

Cone in Halema'uma'u, showing its Steaming Holes.
(From a photograph, taken looking southwestward, Oct. 18, 1886.)

Mr. Dodge remarks, a slope of 163 feet to the northeast wall, 125 feet to the northward, below Kamohoalii, 105 to the middle of the northwest side, below Uwekahuna, and about eighty feet along the short radius to the southeastward. The flow had also encroached upon the south bluffs of Kilauea, and covered the older formation at the head of the bay near Holoholokolea, so that at the extreme south angle in the bluffs a further rise of forty feet, more or less, would cause Kilauea to outflow toward the sea.

Mr. Dodge also mapped and measured the debris-cone of Halema'uma'u, which Professor Van Slyke had found already "upheaved" in Halema'uma'u, and determined the height of some of its summits as given on the map. The cone he found to have a breadth from northeast to southwest, of 1,080 feet, from east to west of 1,100 feet, from northwest to southeast of 930 feet. Consequently, as the width of the Halema'uma'u basin from east to west was 2,300 feet, the depression or trough around the base of the cone was 500 to 700 feet on either side. The highest point in the cone scarcely rose above the level of the margin of the Halema'uma'u basin.

The basin around it was becoming gradually filled by small outflows of lavas discharged from vents opened over its floor, especially near the base of the cone, and near the wall, where were many small cones and blowholes. But outside of Halema'uma'u, evidences of much heat were confined to three or four places.

Further, Mr. Dodge obtained evidence that the floor of the basin with the cone upon it was *rising bodily;* and his observations made on his arrival and before he left indicated that the elevation was going on "at the rate of nearly a foot a day." This he further confirmed by later observations; and on the 14th of January, 1887, wrote that "it was all rising slowly as though floating on the surface of the new lava-lake;" and that the height gained thereby

above the sea-level since October was probably two hundred feet.

The material of the cone he describes as coarse angular debris, with finer fragments, the same that Mr. Emerson found to be the lining of the basin. The structure of the north end — and the rest was all similar — is well shown in Plate IV., from a photograph taken in January, 1887, looking westward. The steaming depression at its base is part of the Halema'uma'u basin. The stratified wall beyond is the west wall of Halema'uma'u; and that above, also stratified, is the west side of Kilauea. Above this faintly in the distance is the dome of Mount Loa, covered with January snows.

The interior of the cone was inaccessible on account of the vapors; but from the flashes of light seen over it at night, Mr. Dodge inferred that there was some action. His native guide said to him, "Plenty fire."

In various places over the exterior, as when seen by Mr. Van Slyke, there were "openings emitting dense bluish-white vapors under considerable pressure, the mouths of which were coated with deposits of sulphur and at night in some cases glowed with red heat."

Plate V. shows the condition in October. The photograph, of which it is a copy, was taken on a cloudy day, and hence the structure of the cone is not distinct; but the steaming apertures are nearly as described by Mr. Van Slyke. The surface in the foreground is that of the Halema'uma'u basin on the northeast side; and the walls beyond are, as before, those of the Halema'uma'u basin and of Kilauea, — the former one hundred to one hundred and fifty feet in height.

Plate VI. represents the cone six or seven months later, in the spring of 1887. Progress had been made of a kind that threatened the life of the cone; for the steaming apertures in its side had become steaming vents of considerable length, too copious in vapors to admit of approach.

Cone in Halema'uma'u.
(From a photograph, taken looking south of west in the spring of 1887.)

Three or four months later, in August, 1887, at the time of the author's visit, the Halema'uma'u cone, as seen from the Volcano House, nearly three miles distant, had the appearance shown in the following figure, the vapors being omitted. Its top was high above the rim of the Halema'uma'u basin, owing to the rise which had taken place. The

Cone in Halema'uma'u, August, 1887.

cone was found to be literally a debris-cone, not a lava-cone or cinder-cone in any part; and the debris was like that of fallen walls of lava, not of loose scoria such as might have come from the central vent of a cone. No eruptions of lava or scoria from the central depression had been at any time observed, and there was no evidence visible over the surface that any such ejections had taken place. In the night view from the Volcano House the dense vapors on the east and west sides were lighted from the lavas below, but none over the centre of the cone, where there was apparently only feeble action.

In the basin about the cone, the chief boiling lava-lake was on the west side, in full view from the top of the west wall. The lake was about 150 by 175 feet in its diameters. Although mostly crusted over, it showed the red fires in a few long crossing lines (fissures), and in three to five open places, half-way under the overhanging rock of the margin where the lavas were dashing up in spray and splashing noisily, with seemingly the liquidity of water. Now and then the fire-places widened out toward the interior of the lake, breaking up the crust and consuming it by fusion; yet at no time was there a projection of the lavas in vertical jets in a free-boiling way; nor was it too hot to stand on the border of the lake if only the face were protected. Al-

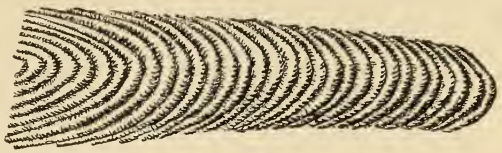
though relatively so quiet, the mobility of the brilliant splashing lavas made it an intensely interesting sight. Occasionally the red fissures widened by a fusing of the sides as the crust near by heaved, and the lavas flowed over the surface. It was evident from the cooled streams outside, that now and then more forcible movements take place, followed by outflows over the margin; when the whole lake is in action. There were no true well-defined jets rising and falling over any part of the surface, like those of 1840, — a condition requiring a little more heat; but the splashing at the margin, also due to the escape of vapor-bubbles, had all the freedom of movement of splashing waves on a sea-coast. The existence of the half-covered caverns along the margin, which the descriptions show to have been the most common feature for a score of years, was owing to the protection from cooling given by the overlying rock. All parts of the basin had been overflowed from fissures or temporary lava-pools.

One of the striking features of the cooled lava-streams over the bottom of Kilauea, and also of those outside, over its slopes and over those of Mount Loa, are the series of parallel curved wrinkles, which give the look of tapestry folds to the surface. They are well shown in the following photograph (Plate VII.), which gives a good general idea of the floor of Kilauea as left by the lava-flooding of 1885.

While looking at the small western lava-lake in Halema'uma'u, which has since been named the "Dana Lake," the making of the tapestry-like folds was well exemplified. A stream of lava came out from beneath the wall of the debris-cone and flowed obliquely across the lake, making the folds or wrinkles by its onward movement in the thin crust which surface-cooling had produced; and the wrinkles were convex down-stream because of the greater velocity at centre. The accompanying figure represents, reduced, a small portion of the stream. The wrinkles also formed over the lake along-

LAVA-FLOOR OF KILAUEA.

side of fissures in the softened and nearly melted crust. At one time a lateral shove took place along one of the fissures in the crust of the lake, and the next moment the margin was rolled over into a long fold or wrinkle, and then, by the more rapid movement of the middle portion, a large part of the fold became twisted into a rope. Thus fold follows fold, and a group or series of rope-like folds results.

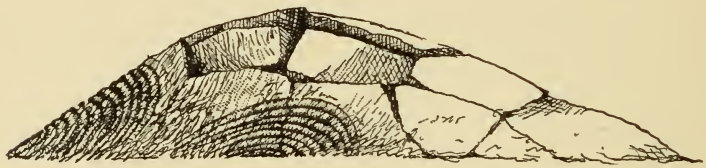


The tapestry-like folds of the surface of streams are sometimes folds simply in the scoria-crust; but they commonly consist of the more solid lava also, or of that alone in case the scoria-crust is absent. Sometimes, in connection with the making of the long ropes, the crust, where thin, becomes bent upward so as to have a long empty space a foot or two deep beneath the brittle cover. It is a trap for the incautious traveller, but it usually startles without injuring, yet serves to point a paragraph about the dangers of the crater.

Over the bottom of the crater there were many bulgings of the lavas into oven-like shapes, having a height of fifteen to twenty feet. Such bulgings are common over all lava-streams, and, as already stated, are often called "billows" and hummocks, and some of them have twice the height of any seen in Kilauea. They look as if they had been produced by a sudden generation of vapors from some volcanic source beneath or from water or moisture passed over by the flowing stream.

In many places evidence was plain that the bulging had taken place after the flow of a lava-stream, though before complete consolidation. This evidence was afforded by the tapestry folds on the bulged surfaces, they being upside down; that is, the folds were often convex upward instead of downward, as in the following figure. The tapestry folds indicate

the direction of movement; and when thus upside down, they prove that they had been turned out of their original position. These bulgings or domes are generally more or less cavernous within, and sometimes cover large chambers; they have usually broken sides with some displaced blocks, as here represented. The breaking up of such domes seemed



to be due in part to contraction and want of support through the cavernous condition beneath. Some of those in the crater had evidently been further crushed by the push of a subsequent lava-flow.

The sulphur vapors probably take part in the making of such dome-shaped elevations. And when so, the space below may have the roof covered with a crust and stalactites of glauber salts, or with a thin crust of gypsum, as often met with in Kilauea, the vapors having contributed material for the sulphuric acid, and the labradorite of the lavas, the soda or lime.

Throughout the crater the lavas had the thin, fragile, or separable scoria-crust or scum, mentioned on page 70 as characteristic of lavas from the overflow of boiling lakes of 1840. But this crust appeared to be thinner than it was in 1840, — only one to two inches thick instead of two to four, as then reported. And as there was vastly greater freedom in the ebullition in 1840, it may well be that the scum of the boiling vats of that period was much thicker than now.

But some of the lava streams have no crust. This results when the lava of an outflow exudes through fissures made in the hardened crust that covers it, or when it comes up through deep fissures, and is not derived from the boiling lakes.

Such lava is ordinarily glassy for half an inch or less externally, but instead of being scoriaceous, the glass is nearly solid and part of the solid lava. The lava flowing beneath the crust of cooled rock had parted with its scum, and that from great depths never had any.

The occurrence of *visible flames* at night over the liquid or semi-liquid lavas of Halema'uma'u, observed by Mr. Brigham and mentioned on pages 88, 96, was one of the interesting points confirmed at the time of the author's visit of 1887. They were seen to rise within the area of the lake where heavings and breakings of the lava-crust took place, and not where the fires were most active. The flames were one to three feet in height. They were very pale in color, and slightly greenish rather than bluish. The author does not claim himself to have seen the flames, — the rains of the evening and a cold from a thorough wetting on a long excursion having prevented his joining the party. But critical observers were of the number, — as Mr. Emerson of the Government Survey, President Merritt of Oahu College, Rev. S. E. Bishop, and others, — and the testimony was unanimous.

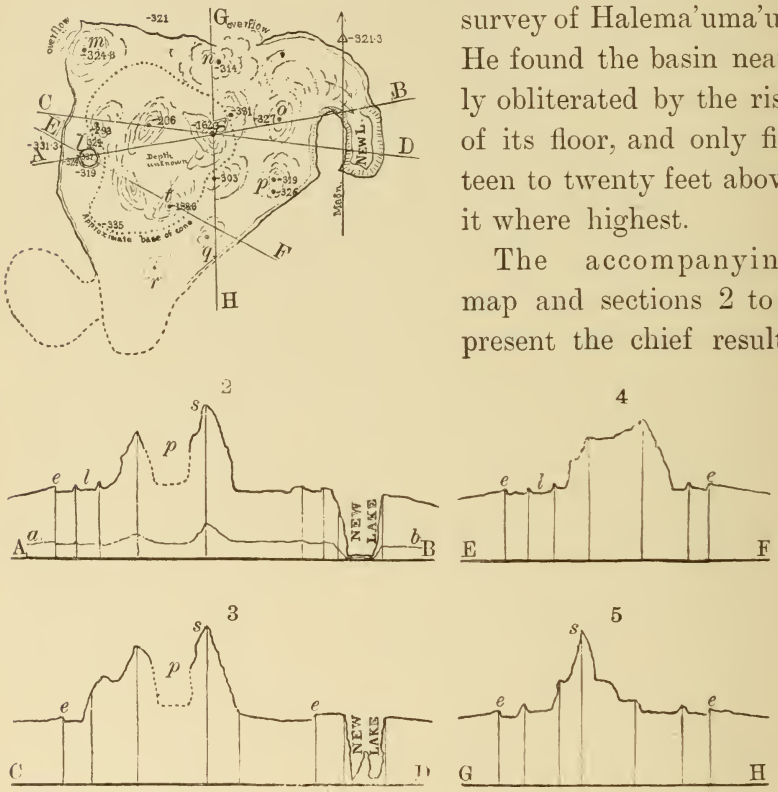
In September, 1887, a month or so after the author left the volcano, the photograph of the Halema'uma'u cone was taken which is reproduced on Plate VIII. It is essentially the same as the cone of August. . The change since the spring of 1887 is apparent in the longitudinal division of the west wall into two, so that the vapors rise east of a western section for nearly the whole length. The great cone was evidently in process of dissolution.

By March 8, 1888, the cone had risen so high that the summit was "on a line with the outside walls of the crater beyond it, looking from the Volcano House;" and the floor of the basin had risen likewise, so as to be but forty or fifty feet below the top, — facts which imply a rise of thirty or forty feet since the middle of August, 1887. Moreover, the

eastern side of the cone, which appeared to be partly separate in the later photograph (Plate VIII.), "has slipped down a little and changed considerably in shape." [1]

In July, 1888, Mr. F. S. Dodge made a new survey of Halema'uma'u.[2] He found the basin nearly obliterated by the rise of its floor, and only fifteen to twenty feet above it where highest.

The accompanying map and sections 2 to 5 present the chief results



1. Map of Halema'uma'u in July, 1888, by Mr. F. S. Dodge, reduced to one fourth. 2 to 5. A B, C D, E F, G H, courses of the sections. 2 to 5. Sections by Mr. Dodge of Halema'uma'u in July, 1888.

of his survey. The scale of the map is two thousand feet to the inch, which makes the distance across the basin from east to west (New Lake not included) a little over three thousand feet. The outline of the debris-cone at

[1] Mr. J. H. Maby, of the Volcano House, American Journal of Science, 1888, xxxvi. 14.

[2] American Journal of Science, 1889, xxxvii. 48. See also a letter from President Merritt, Ibid., p. 52.

DEBRIS-CONE IN HALEMA'UMA'U.

(From a photograph, taken looking southwestward, September, 1887.)

base is approximately indicated by the dotted line. The numbers give the level, below the Volcano House datum, of three points at the top of the cone as well as of the floor of the basin and of the crater outside. At *m*, *n*, *o*, *p*, *q*, *r* are small discharging cones, ten to twenty feet high. Two of these small cones, *m* and *n*, were at such a height, owing to the rising of the floor of the basin, that their lava-streams overflowed the rim of the basin; and from *o* the lavas had flowed into New Lake. *s* and *t* are the higher summits of the cone, and "New L." means *New Lake*.

Figs. 2 to 5 are four profile sections by Mr. Dodge (A B, C D, E F, G H) of the basin and its cone. The height in these sections is exaggerated five times; the scale is made four hundred feet to the inch, and the horizontal two thousand feet; but in Fig. 2, the profile *a b* has the true proportions. In 2 and 3, *p* is the pit within the debris-cone. No attempt to obtain the depth could be made on account of the discharging vapors. *e* is the edge of the basin of Halema'uma'u; *l*, Dana Lake. The projection above the floor of New Lake in Fig. 3 is due to the "stranded floating island."

The time from March, 1886, to July, 1888, a little over two years, was sufficient for the refilling of the deep basin of Halema'uma'u and also of New Lake, and for the renewal of the great outflows over the floor of the crater. This condition continued until May, 1889, when, as I learn from Mr. Baker, there was a subsidence of eighty feet in the floor of Halema'uma'u, which carried down the large central debris-cone, and all else on the floor, and made walls of eighty feet again about the great depression. Dana Lake was between the walls and the cone; but on July 4 it was as active as usual, and a stream flowed from it toward the cone. A stream of lava issued in May from a fissure in the floor of Kilauea, some distance from Halema'uma'u; and this appears to have drawn off the lavas beneath the floor of the basin, and so dropped it down the eighty feet.

5. General Summary, with Conclusions.

From the foregoing review of publications on Kilauea, it appears that the knowledge we have about the changes in the crater embraces facts that are fundamental to the science of volcanic action. This will be made more apparent by the Summary and Conclusions which follow. It will be convenient to consider, first, the Historical Conclusions, and, secondly, the Dynamical.

I. HISTORICAL CONCLUSIONS.

1. Periodicity or not in the Discharges of Kilauea.

In the sixty-three years from 1823 to 1886, there appear to have been at least eight discharges of Kilauea. Four of them were of prime magnitude, — those of 1823, 1832, 1840, and 1868, — distinguished by a down-plunge in the floor of the crater, making in each case a lower pit several hundred feet deep. Others, as those of 1849, 1855, 1879, 1886, were minor discharges, discharges simply of the active lakes, without any appreciable or noticed sinking of the floor of the crater. The eruption of 1849 may be questioned. Other subterranean discharges may have occurred since 1840, of which no record exists. Even small breaks below might empty Halema'uma'u; and they often do more or less, as the floor of Kilauea between eruptions rises.

The mean length of interval between the first three eruptions was eight to nine years. The great eruption of 1789, the only one on record before that of 1823, occurred thirty-four years back of 1823, or $4 \times 8\frac{1}{2}$ years; and the 1868 eruption was $3 \times 9\frac{1}{3}$ years after that of 1840.

The above approximate coincidences in interval and multiples of that interval seem to favor some law of progress. But it is not yet proved that they have any significance. The minor eruptions which have been referred to above have intervals

varying from six to thirteen years. Moreover, looking to the summit crater of Mount Loa for its testimony, we find still greater irregularity, the successive intervals between its six great outflows from 1843 to 1887 being $8\frac{1}{2}$, 4, $3\frac{1}{2}$, 9, $12\frac{1}{2}$, and $6\frac{1}{4}$ years.

Dependence of the Activity on Seasons of Rains. — A relation to the rains was suggested by Mr. Coan; and there is some foundation for the opinion in the fact that the times of occurrence of the Kilauea discharges come mostly within the four months, March to June, as shown in the following table:

1823	March?	1849	May.	1879	April 21.
1832	June (Jan.?)	1855	October.	1886	March 6.
1840	May.	1868	April 2.		

In addition, there was a brightening of the fires around the crater in October of 1863, and again in May and June of 1866; whether followed by a discharge of the Great Lake or not is not known. The future study of the crater should have special reference to this supposed meteorological connection.

2. Mean Rate of Elevation of the Floor of the Crater after the Great Eruptions.

After the eruption of 1823, between the spring of that year and October of 1829, an interval of $6\frac{1}{2}$ years, the bottom, if the depth was 800 feet as inferred after the measurement of the upper wall by Lieutenant Malden, rose at a mean annual rate of 138 feet, or, taking the depth at 600 feet, of 93.3 feet. Lieutenant Malden's 900 feet for the upper wall, sustained after explanation on page 51, may need reduction, on the ground that the present width of the crater is greater than in 1825, owing to falls of the walls; but it is useless with present knowledge to make any definite correction. Only general results are possible.

After the 1832 eruption the lower pit in February of 1834 was 362 feet deep, by the barometric measurement

of Mr. Douglas, as explained on page 57; and in May of 1838, about $4\frac{1}{2}$ years later, it was filled to within forty feet of the top; whence the mean annual rate of $71\frac{1}{2}$ feet.

After the 1840 eruption, between January, 1841, and the summer of 1846, $5\frac{1}{2}$ years, the 342 feet of depth, found for the lower pit by the Wilkes Expedition, was obliterated, and the floor was raised on an average forty or fifty feet beyond this; a rise of 400 feet in the $5\frac{1}{2}$ years would give, for the mean annual rate, $72\frac{3}{4}$ feet.

Subsequent to 1846 the rising of the floor was slower. Between 1846 and 1868, twenty-two years, the rise over the central plateau is estimated at two hundred feet. It is not certain that subsidences in the plateau of greater or less amount did not take place at the eruptions of 1849 and 1855, or at other times.

3. Levels of the Floor after the Eruptions of 1823, 1832, 1840, 1868, and 1886.

The measurements of depth already given and the mean annual rate of progress deduced are approximate data for determining the depth of the lower pit as it existed immediately after the great eruptions.

The depth after the 1823 eruption is considered above. To arrive at the depth after the 1832 eruption, the depth obtained in 1834 by Douglas has to be increased by an allowance for change during the previous year and a half, which, at the rate arrived at above, would give four hundred and fifty feet. This is so much less than the estimate of Mr. Goodrich, mentioned on page 56, that it is almost certainly below rather than above the actual fact.

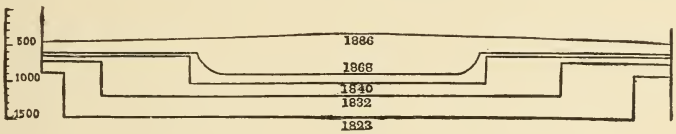
For the depth in June, 1840, the Wilkes Expedition measurement (342 feet) should be increased for a preceding interval of seven months, which, at the rate deduced above for the next four years, would make the amount about 385

feet. In 1868, according to the two estimates for the lower pit, the depth was about three hundred feet. Mr. Severance, of Hilo, informed me, in August, 1887, that the pit in 1868 was as deep as in 1840. The lower estimate is adopted beyond. In 1880, the lower pit of 1868 had wholly disappeared, and, according to the description of Mr. Brigham (p. 96), the bottom of the crater had already the form of a low eccentric cone, the surface rising from the foot of the encircling walls to the summit about Halema'uma'u. This has continued to be the form of the bottom, and the Government map gives the present depth. (See Plate III.)

The following table contains the above deduced figures for the depth of the lower pit, the height of the *highest part* of the western wall, and the level of the centre of the pit below the top of the western wall.

	Depth of Lower Pit.	Height of Western Wall above Ledge.	Height of Western Wall above Centre of Bottom.
After eruption of 1823	600 (800 ?)	900 (?) Malden	1,500 (1,700 ?)
1832	450 (600 ?)	715 Douglas	1,165 (1,315 ?)
1840	385	650 Wilkes [1]	1,030
1868	300	600 (550 ?)	900 (850 ?)
1886	0	500 Gov't Survey	380

These numbers have much instruction in them, notwithstanding all uncertainties. The following diagram based on



them represents a transverse section of the crater at the several levels of the floor and black ledge. The minimum depths for 1823 and 1832 are here accepted, there being in them no probability of exaggeration.

The sides of the pit in this section are made vertical

[1] The Wilkes Expedition appears to have made the place of encampment the datum point. It was just west of the solfatara depression, but the exact position is not precisely known.

from 1823 onward, — an error which there are no data for correcting.

The diminution since 1823 in the height of the western wall above the black ledge is probably due almost wholly to the *flooding* of the black ledge. According to the numbers this diminution was about a hundred and eighty-five feet from 1823 to 1832, sixty-five from 1832 to 1840, and one hundred and sixty feet since 1840. But subsequent to 1840, as Emerson's map shows, the diminution of level along the black ledge or lateral portion of the pit has been much less than over the central, the amount of diminution at centre having been at least two hundred feet, and about Halema'uma'u two hundred and fifty to three hundred feet.

The bottom of the emptied basin of Halema'uma'u after the eruption of 1886 was nine hundred feet below the Volcano House; and this was fifty to a hundred feet above the liquid lava of the basin in 1840.

The relations between the amounts discharged in 1823, 1832, 1840, and 1868 could be approximately inferred from the size of the lower pit as determined by the mean breadth of the black ledge, if the width of the crater were the same at all periods. But in addition to other uncertainties we have that arising from sloping walls, — and very sloping on the southeast side. The pit of 1823 should therefore have been narrower at the black-ledge level than that of 1840. Still the width of the ledge in 1823, according to all the observations and maps, was so very narrow compared with that in 1840 that we may feel sure of the far larger amount of the earlier discharge. But the depth of the lower pit was also greater in 1823; and this requires an addition of one half to the amount which the area of the lower pit suggests, if not a doubling of it.

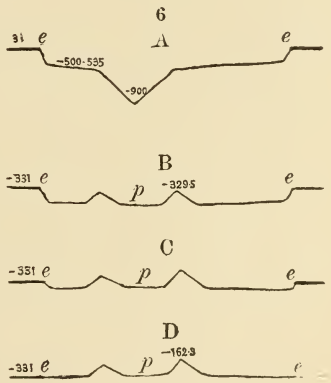
For an estimation of the discharge of 1832 we are still more uncertain as to the mean width of the ledge. But that the ledge was narrow — much like that of 1823 — is most

probable. In 1868 the down-plunge, according to the most reliable estimate, was a fourth less than in 1840, the depth of the pit being not over three hundred feet.

There are no sufficient data for putting in figures the relative amounts of discharge at the great eruptions. But the general fact of a large diminution in the amounts since the first in 1823 is beyond question. It has to be admitted, however, that we can hardly estimate safely the discharge in 1868 from the size of the pit then made, since the thickness of the solid floor of the crater may have prevented as large a collapse in proportion to the discharge. But it did not take place until twenty-eight years had passed after 1840, and this strengthens the evidence as to an apparent decline in the outflows, whatever be true as to the activity. The following eighteen years produced only minor eruptions.

4. Progress in Halema'uma'u since the Eruption of March, 1886.

In April, 1886, a month after the eruption, Mr. J. S. Emerson found the basin 590 feet in depth at middle, and 175 to 200 feet deep over a broad border region. The condition is represented approximately (from Mr. Emerson's measurements) in the profile section A. The cone had already become, by Professor Van Slyke's estimate, a hundred and fifty feet high in the next three months. The sections across the basin through the cone B, C, D, illustrate the progress in the lifting of the cone and the floor of the basin, B being the condition reported in Mr. Dodge's survey of the first week of October, — six months after Mr. Emerson's survey, when the highest peak of the cone was only two to five feet above the rim of



the basin; C, that approximately at the time of the author's visit in August, 1887; and D that of Mr. Dodge's last survey in July, 1888, when the cone was almost wholly emerged.

From the levels obtained by Mr. Dodge at his two surveys in October, 1886, and July, 1888, and by Mr. Emerson in April, 1888, we have data for determining the rate of change of level. (1) The change in the western rim of Halema'uma'u was nothing; (2) in the summit *s*, 167.2 feet; in the summit *t*, 171.4 feet. The time during which this rise of approximately 170 feet took place was about 650 days, giving for the mean daily rate of rise 3.15 inches. The rise was most rapid during the first year, Mr. Dodge making the rate in October, 1886, a foot a day.

The small ejections going on over the basin outside of the cone during the two years past, raised to some extent the level of the floor. But whatever the amount it does not affect the calculation, this being based on changes in the level of the summit, which received no additions from ejections or any other source.

The conclusion of Mr. Dodge that the cone within Halema'uma'u and the floor of the basin about it had been "floated upward" on the rising lavas appears, therefore, to be the only satisfactory explanation of the change of level.

Finally, in May of 1889, an eruption over the floor of Kilauea (or some other way of discharge) dropped the floor of Halema'uma'u, with the cone, eighty feet again, restoring nearly the condition of August, 1887. This is the ordinary way with Halema'uma'u. Its discharges from time to time help in the raising of the Kilauea floor, and in the process its own floor loses in level.

5. Other Points in the Topographic History of the Kilauea Region.

Besides the points considered, the chief events in the topographic history since 1823 are (1) avalanches and subsidences

along the border of the crater, and (2) overflowings and changes of level over the bottom.

Down-falls of the walls and sinkings of the borders are reported as having been common during periods of eruption and earthquake; but direct testimony as to the amount at any time does not exist.

Besides the great fissures of the northern border of the crater, near the path of descent, with the subsided belts between, and the many fissures of the solfatara depression just back, others exist farther north and east, to a limiting wall, about forty feet high, which is evidently a fault-wall. This wall is about two thousand feet from Kilauea at the northwest corner, and diverges eastward to about five thousand feet, and then bends around southward so as to embrace Kilauea-iki within the large northern border region of fissures and subsidence.

Deep and wide rents extend also along the whole western border of Kilauea, generally two or more together; and near the highest station, Uwekahuna, there were six of them, parallel to one another, in August, 1887. South of this station, between it and the southwest angle of the crater, the fissures are continued over a large depressed border, five to fifteen hundred feet wide, lying between a precipitous ridge — fault-plane — on the west and the crater. North of Uwekahuna the evidences of subsidence visible in 1887 were small; but south of it the surface had different terrace-levels, showing great and various sinkings of the surface. Almost in front of Uwekahuna, bordering the Kilauea wall, there was a surface, 200 to 298 feet below the level of this station, according to the Government maps, which is plainly, as seen from below, a result of subsidence; and various other terrace-levels existed farther south. On the east side of Kilauea also there are fissures parallel to the walls; and large depressed areas exist between Kilauea and the two adjoining craters. Fissures extend northward to the east of

Kilauea-iki, as noticed by the Wilkes Expedition in 1840, and new openings there, near the Keauhou road, were reported as opened in March, 1886, at the time of the eruption.

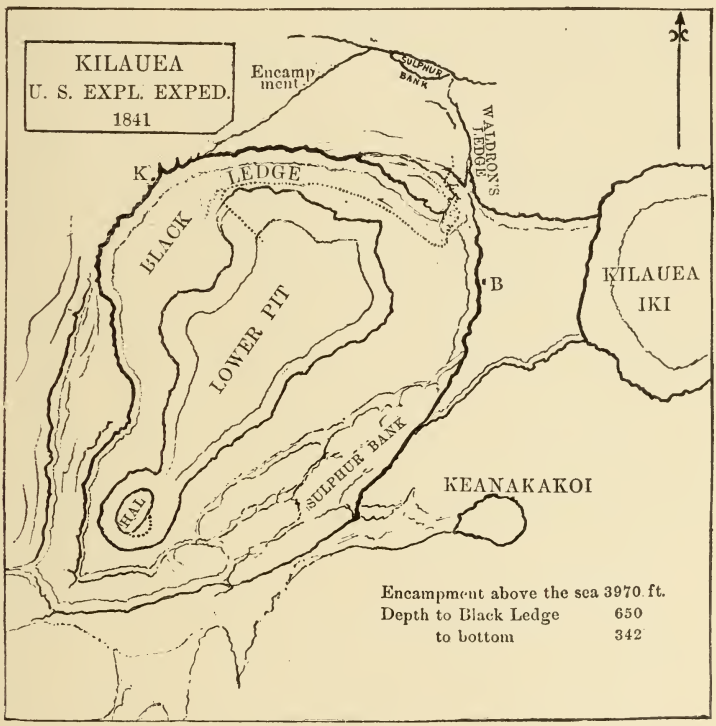
The wall on the northeast side of Kilauea near the path of descent, called Waldron's Ledge (after a purser in the Wilkes Expedition), is one of the highest and most stable parts of the walls, being but eleven and a half feet below the level of the Volcano House datum. It is a bare-faced, vertical precipice, showing stratified lavas to the top. Like Uwekahuna, it seems to be an exception to border instability. But it stands on the brink of the most unstable region, — that of the north side. In a walk along the base of the precipice there was in August, 1887, a freshly uncovered portion of the rock at bottom for a height of two to three inches, showing that a recent sinking adjoining it had taken place, or that one was then in progress.

This border-belt of fissures and subsidences, if reckoned as part of the Kilauea fire-region, or region of disturbance, adds five thousand feet to the length of the region, and nearly doubles the width across the northern half. There are long fissures also over the region southwest of the crater, some of which were reported by the Mission Deputation of 1823.

It is an interesting and important fact that while the fissures about the northeast end of Kilauea are *concentric* with the outline of the crater (Kilauea-iki being included with it), those at the south end are nearly all *longitudinal*, or in the direction of the longer diameter, southwestward. Moreover, as is well known, the latter extend on for twelve to fifteen miles to the southwest. There are many of them, — more than is shown on any map or recorded in any description; and some are very deep in places, giving off hot air, steam, and sulphurous acid fumes in great volume. While some of them date from 1868, and others from 1886, still others existed back of all records. The subsidence that

has gone on over this southwestern fissured area has not left any satisfactory evidence of its amount. We know only that (as the Government map teaches) the surface is about 280 feet *below* the level of the Volcano House, and 395 feet below that of the Uwekahuna station.

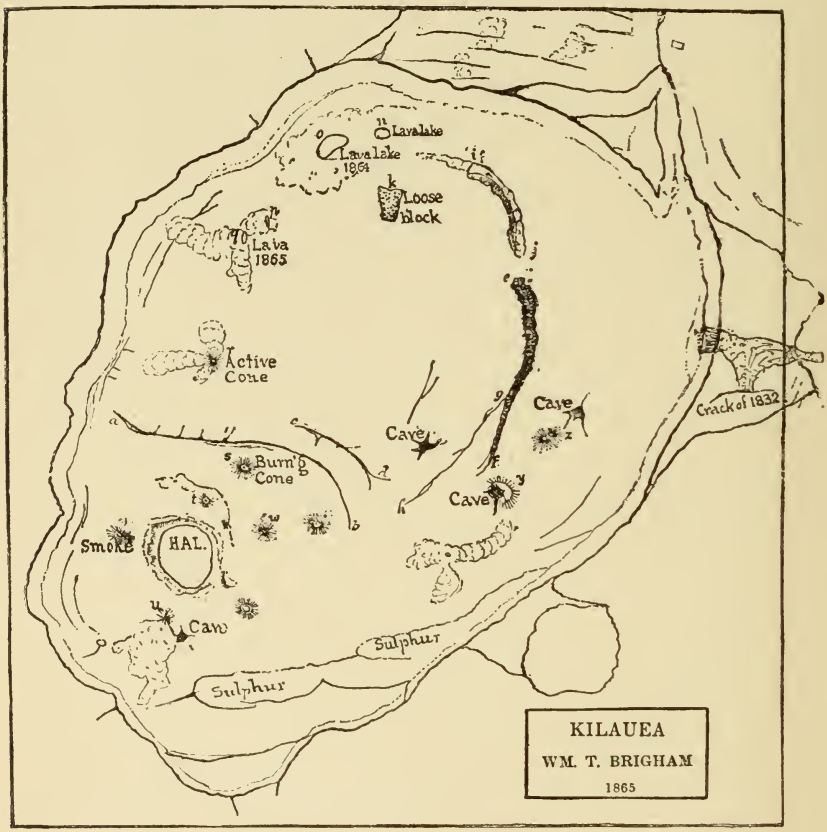
In view of the great numbers of deep fissures about Kilauea and the many fault-planes and sunken areas, the fact of extensive subsidence cannot be doubted. Mr. Brigham has estimated[1] that the crater in 1880 was five per cent larger than it was eighteen years before. The increase in mean diameter on this estimate would be three hundred feet. This estimate appears to be much too large.



Of the gradual changes over the bottom of the crater pretty full records are given in the preceding pages. For defi-

[1] American Journal of Science, 1887, 3d series, xxxiv. 20.

nite information on this point, and especially with regard to changes in general outline, we should naturally look with the greatest confidence to the maps that give the results of personal surveys. We have two such maps, — that made personally by Wilkes in 1841 and that by Brigham in 1865, — besides the recent map by the Hawaiian Government, under Professor Alexander's charge, completed in 1886. The first is here



referred personally to Captain Wilkes, because his "Narrative" says: "I measured my base and visited all the stations around in turn." For convenient comparison the reduced copies of Wilkes's and Brigham's maps are here reproduced. For that of the Government Survey, see Plate III.

In using the maps a difficulty is encountered at the outset in consequence of a discrepancy between the first two of the maps and that of the Government Survey as to the dimensions of the crater. Accepting the latter as right, the scale of each of the others should be diminished about an eighth to bring the three maps into correspondence. The maximum diameters in Wilkes's map, using his own scale, are 16,000 and 11,000 feet; while, according to the Government map, they are about 14,000 and 9,800 feet; and the length of the line from K to B on the former is 10,000 feet, and on the latter 8,500 feet. It is certain that the crater in 1840 was not *larger* at top than now. Mr. Brigham's map appears to have been carefully made, but for some reason it requires the same correction. This correction makes the scale of Wilkes's map 5,000 feet to the inch, as stated on page 65. Such a discrepancy unavoidably throws doubts over other parts of the maps. But while closer study increases confidence in Mr. Brigham's, the result is not so satisfactory with the Wilkes map. The following remarks suppose the scale of the two maps to have been corrected.

Wilkes's Map of Kilauea. — The relations of the map made by Captain Wilkes to that of the Government Survey is exhibited on Plate IX., the outline of the crater from the former being drawn over the latter where it is prominently divergent. This diverging part of the outline is lettered A B C D E; D E shows the outline of the southeast Sulphur Bank of 1840. Besides this, the outline of the black ledge of 1840 is indicated by the line L L L, and its surface by cross-lining. Some important features from Brigham's map also are drawn in and indicated by italic letters. These include small lava-lakes, the outline of Halema'uma'u as given by him, small cones, fissures, etc.

Plate IX. shows, in the first place, a general conformity between the *eastern* wall of the Wilkes and the Government maps, but a far greater width of Sulphur Banks in that of

1840. These Sulphur Banks have become submerged by the lava-flows of later time, as remarked as long ago as 1868 by Mr. Brigham, and thus the floor of the crater has in this part been extended eastward about twenty-five hundred feet. This change there is no reason to doubt.

In the second place, there is no conformity between the maps in the southern half of the western wall. On the contrary, in Wilkes's map, south of the Uwekahuna station, the west wall (A B C, on Plate IX.) is twelve to fifteen hundred feet inside of the position of the existing wall as given on the Government map; showing, apparently, a very great topographical change on that side of Kilauea since January, 1841, and one of the highest interest, — a change that, if a fact, had been brought about either by subsidence or by overflowings of lava-streams, and had added nearly ten million square feet to the area of the crater.

Looking about for other evidence of this change, and finding no allusion to it in Mr. Coan's reports on the crater during the period, and nothing in Mr. Lyman's paper of 1851 or his map of 1846, but, on the contrary, a general conformity in Lyman's map to that of the recent survey, I was led to question the unavoidable conclusion, although it involved a doubt of the Wilkes map. A consequence of the doubt was my sudden determination in the summer of 1887 to revisit Hawaii and sustain the conclusions from Wilkes's map if possible; for they made too large a piece in the history to be left in doubt. Mr. Drayton's sketch (Plate II.) suggested the method of deciding the question.

The conclusion arrived at while on the ground was that Drayton's sketch of 1840 represented sufficiently well the *present* outline of that part of the crater; that is, the outline of the crater of 1887. Consequently, if the west wall in 1840 had essentially the same position as in 1887, Wilkes's map of the southern half of its western wall is twelve to fifteen hundred feet out of the way.

To make this large correction on Wilkes's map involves some other large changes; namely, the widening of the black ledge west of Halema'uma'u; and also a widening of the Halema'uma'u part of the lower pit with the entrance-way to it. Both changes are favored, or rather required, by Drayton's sketch. In Plate IX. the entrance-way referred to has thus been widened (on the ground of Drayton's sketch chiefly), from Wilkes's eight hundred feet at top of wall to about fifteen hundred feet. The dotted line L′ L′ L′ on the same plate is believed to show the probable limit of the 1840 black ledge along the west border of Halema'uma'u.[1]

So large an error in so small a map excites an uncomfortable query as to all the rest of its details; fortunately not, however, as to the depth of the crater and its lower pit, since this was obtained by the independent measurements of two of the Expedition officers, Lieutenants Budd and Eld. Moreover, the map may be used for some general conclusions.

The point from which Drayton's sketch was probably taken is marked *Dn* on Plate IX.; this is south of Wilkes's encampment. It may have been on the higher land just west of this point.[2]

The sketch has three headlands along the west wall. Of these, only the second and third exist as they then were. The first or nearest stood, as the sketch shows, between the Uwekahuna summit and the second of the deep western bays on Wilkes's map of the lower pit, — a spot where great subsidence has taken place in the western wall, east or southeast of the Uwekahuna station; and the sketch appears to

[1] Another smaller change is proposed in the eastern outline of the lower pit, near *e*, suggested by Brigham's map. No attempt is made to give, on the Government map, Wilkes's outline of the southeast angle of the crater, as the existing features offer no available suggestions.

[2] While the sketch bears evidence of being generally faithful to the facts, the foreground appears to be modified for the artistic purpose of giving distance to the rest.

be sufficient testimony for the reality of this subsidence and its amount.

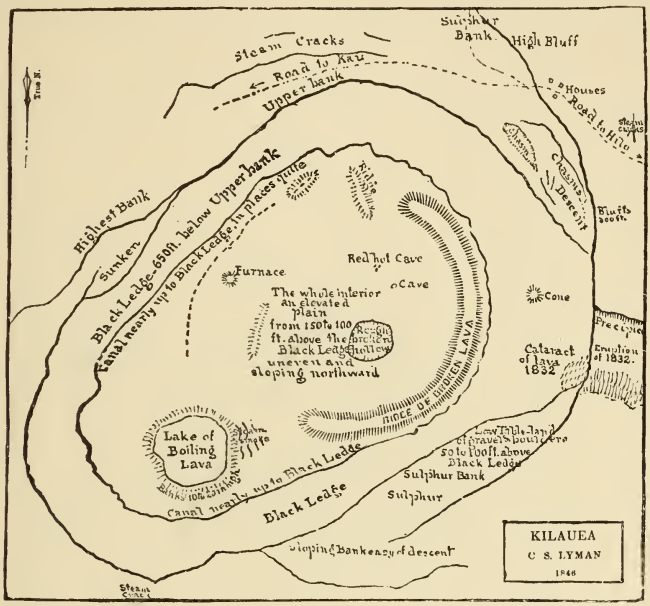
Looking again at Wilkes's map, on page 133, it is seen that, as already stated, the outer eastern wall has the same position that it has on the Government map, but that the western wall of Wilkes is not continuous with the southeastern, but is an independent one put in more to the eastward; and here came the error. The error is so extraordinarily great that we sought, while at the crater, for some extraordinary excuse for it. We concluded (Mr. Merritt and myself) that Captain Wilkes in his visit to "all the stations around the crater in their turn," on reaching the high Uwekahuna summit, instead of relying on his angles, probably took the shorter way of sketching in the ridges that stood to the southeast and south; and that he was led by insufficient topographical judgment to throw the wall, together with the parallel ridge outside of it, too far to the eastward. The error, as we saw when there, is an easy one for him to have made. This cramped the map to the southward about the Great South Lake; but the angles taken from other stations were not enough to serve for the needed correction, and the sketching was allowed to control the lines.

An important error also exists in Wilkes's determination of the longitude of his encampment near the crater. The Surveyor-General of the Islands, Professor Alexander, informed me that the position Wilkes gives Kilauea is eight and a half minutes too far west; and that the error affects all the southeastern quarter of his map of Hawaii including the position of the coast-line. His longitude of the summit of Mount Loa is correct.

Mr. Brigham's Map. — Mr. Brigham's map is a register of the facts of 1864–1865, a period just half-way between 1841 and 1887. It indicates unfinished changes in progress within the crater which were commenced in 1840,

and other conditions that became pronounced only in later years.

The remnants it represents of Lyman's ridge of lava-blocks — the talus of the lower wall uplifted upon the rising floor



of the lower pit, and the same on Mr. Perry's sketch — have already been referred to. That it may be fully appreciated, the reader is directed again to Mr. Lyman's map above, and then to Plate IX., which shows these remaining parts of the long ridge drawn, from Mr. Brigham's map, on the recent map of the Government Survey (lettered *e f, g h*). The ridges are not put as far from the east wall of the crater as on Brigham's map, but are made to accord with the statement of both Lyman and Coan (p. 78) and of Brigham also, that they followed the course of the lower-pit wall of 1840 a little inside of its position, over the site of the original talus. — Wilkes's position of the wall being adopted except for a short distance near *e*. Halema'uma'u, as the dotted line inside of the basin of the Government map shows, was small

in 1864–1865, it being only one thousand feet in diameter and but little raised above the level of the liquid lavas.

Mr. Brigham's map shows also the positions of active lava-lakes in 1864 or 1865 (lettered *i*, *k*, *l*, *m*); and the interesting fact is to be noted, on Plate IX., that two of them, to the northwest (*i*, *k*) lie *at the edge of the black ledge*, while *l*, *m* are a little back of it, but in a line with *i*, *k*.

The long curving line of deep fissures and fault-plane, already referred to as marking the outline of the Halema'uma'u region, is seen on Plate IX., at *a b*, not to be concentric with the Halema'uma'u basin of either Brigham's map or of the recent map, but to that of Halema'uma'u *plus* the New Lake region of 1884 to 1887. Thus in 1865, when Halema'uma'u appeared as a small basin one thousand feet broad (not half its existing breadth), the fissure indicated the presence of deep-seated conditions as to the fires and forces that finally ultimated in its extension over the New Lake area. And the expression of this fact in 1865 was doubled by a second concentric fissure five hundred feet farther north (Plate IX., *c d*). Further, four of the cones mapped by Brigham in the vicinity of Halema'uma'u in 1865 (*p*, *q*, *r*, *s*, on Plate IX.) are inside of the existing Halema'uma'u basin; and one of the others (*o*) is near the north border, and another (*t*) is close by the east side of New Lake.

On Mr. Brigham's map, the position is given of a very large loose block of lava, which is shown at *w*, on Plate IX. It lies, as is seen, in the northwest part of the crater, and is over the lower edge of what in 1840 was an inclined but even lava-plane to the bottom, that had been made in 1840 by an oblique down-plunge, carrying the inner side of the great mass down and leaving the other, that against the black ledge, on a level with the ledge, with a broad fissure between. This sloping way from the ledge to the lower floor is mentioned on page 70. The block probably slid down the slope to its bottom. But in the lifting again of the obliquely

HAWAIIAN GOVERNMENT SURVEY.

W.D. Alexander Surveyor General.

THE CRATER OF KILAUEA, HAWAII.

Surveyed in Sept.- Oct. 1886, by
Frank S. Dodge.
Outlines of Halemaumau and New Lake
and a portion of the Triangulation by
J. S. Emerson.
Map by Frank S. Dodge
Nov '86

With additions from the Maps of Capt. Wilkes and W. T. Brigham.

All elevations are referred to Volcano House Verandah floor which is 4040 feet above Mean Tide.

subsided mass, as the floor was raised and Lyman's ridge was made, this loose block was lifted. The lift along that part of the crater, which was already completed in 1846, consisted in the restoring of the half-engulfed mass with the lava-block on its surface, to its former horizontal position; and this was the position it had when Mr. Brigham's map and observations were made.

It is interesting to note thus how the 1864–1865 condition of Kilauea grew out of that of 1840, and foreshadowed that of 1887. It is worthy of consideration, also, that just as the fault-plane *a b* is concentric with the Halema'uma'u basin *plus* New Lake, so the far greater Kilauea fault-planes, two thousand to five thousand feet north and northeast of the crater, are concentric, not with Kilauea, but with Kilauea *plus* Kilauea-iki.

II. DYNAMICAL CONCLUSIONS.

General Cycle of Movement in Kilauea. — The history of Kilauea, through all its course since 1823, illustrates the fact that the cycle of movement of the volcano is simply: (1) a rising in level of the liquid lavas and of the bottom of the crater; (2) a discharge of the accumulated lavas down to some level in the conduit determined by the outbreak; (3) a down-plunge of more or less of the floor of the region undermined by the discharge. Then follows another cycle: a rising again, commencing at the level of the lavas left in the conduit, — that is, the lavas of the lava-column, — which rising continues until the augmenting forces, from one source or another, are sufficient for another outbreak.

In 1832 the conditions were ready for a discharge when the lavas had risen until they were within seven or eight hundred feet of the top; in 1840, when within six hundred and fifty feet; in 1868, when within five or six hundred; in 1886, when within three hundred and fifty feet. The greater

height of recent time may seem to show that the mountain has become stronger, or better able to resist the augmenting forces. But it also may show a less amount of force at work. In 1823, 1832, and 1840 the down-plunge affected a large part of the whole floor of the crater, which proves not only the vastness of the discharges, but also indicates active lava through as large a part of the whole area preceding the discharge, while in 1886 the down-plunge and the active fires in view were confined to Halema'uma'u and its vicinity. It was not in earlier time, therefore, the greater weakness of the mountain, but probably the greater power of the volcanic forces.

The broad low-angled cone which the volcano tends to make, has a great breadth of stratified lavas to withstand rupturing forces. How great may easily be calculated by comparing a cone of 5° to 8° with one of 30°, the latter the average angle of the greater volcanic mountains of western America; and this suggests important differences in the results of volcanic action independent of those consequent on the possible prevalence of cinder-ejections in the latter. Somehow or other Mount Loa breaks easily — very easily, its quiet methods say — and it seems to be because such rocks, however thick, can offer but feeble resistance to rupturing volcanic agencies.

In the discussion beyond of the operations going on and of their causes, I speak (1) of Kilauea as a Basalt-volcano, the basis of its peculiarities; (2) of the size of the Kilauea conduit; (3) of the ordinary work of the volcano. The origin of the eruptions of Kilauea is considered in connection with that of the Mount Loa eruptions.

1. Kilauea a Basalt-volcano.

The Mobility of the Lavas. — The phenomena of Kilauea are largely due to the fact that it is a basalt-volcano in its

normal state. By this I mean, first, that the rock-material is doleryte or basalt, and secondly, that the heat is sufficient for the perfect mobility of the lavas, and therefore for the fullest and freest action of such a volcano. It is essentially perfect mobility, although there is not the fusion of all of its minor ingredients, that is, of its chrysolite and magnetite. This is manifested by the lavas, whether they are in ebullition over the Great Lake, throwing up jets twenty to forty feet high, throughout an area of a million square feet or more, or when only splashing about the liquid rock and dashing up spray of lava-drops from areas of a few square yards. There is in both conditions the same free movement, almost like that of water, and suggesting to the observer no thought of viscidity. Of the two conditions just mentioned, the former was that of November, 1840; the latter that of August, 1887, and of the larger part of intermediate time.

This mobility is dependent largely on the fusibility of the chief constituent minerals of the lava. Trachyte and rhyolyte are the least fusible of igneous rocks, because the constituent feldspar, orthoclase, is the least fusible of the feldspars; and basalt or doleryte is one of the most fusible, because the feldspar present, labradorite, is of easy fusibility, and it is combined in the rock with the still more fusible augite or pyroxene.

The degree of mobility is dependent also on temperature. It is probable that at the temperature of fusion, or better a little above it, all the feldspars, the least and the most fusible, are nearly alike in mobility. But the lower the degree of fusibility the less likely is the heat to be deficient, or below that required for complete fusion and mobility; and here comes in the great difference among them as regards lavas and volcanoes.

The basalt-volcano has special advantage over all others in this respect, as the copious Mount Loa lava-streams and the

immense basaltic outflows of other regions exemplify. In Hawaii the heat required for the existing mobility is no greater than the deep-seated conditions below the mountain can keep supplied, in spite of cooling agencies from cold rocks, subterranean waters, and the air; it is no greater than it can continue to supply for more than half a century, as the records have shown; and supply freely to the top of a conduit three thousand to thirty-five hundred feet above the sea-level, and even to the top of another conduit but twenty miles off, rising to a height of thirteen thousand feet above the sea-level. The temperature needed for this mobility, judging from published facts, is between 2000° F. and 2500° F. The fusing temperature of augite and labradorite has not yet been determined. We are certain that a white heat exists in the lava within a few inches of the surface; for the play of jets in a lava-lake makes a dazzling network of white lightning-like lines over the surface; and white heat is equivalent to about 2400° F. Considering the height of Mount Loa and the greatness of its eruptions, and the vastness of basaltic outflows over the globe, we may reasonably assume that the temperature needed for the normal basalt-volcano has long been, and is now, easy of supply by the earth for almost any volcanic region; and that the difficulty the earth has in supplying the higher heat, for equal mobility in a trachyte or rhyolyte volcano, is the occasion of the semi-lapidified, pasty condition of their outflowing lavas.

Even if the higher temperature required for orthoclase lavas were always present quite to the surface in the volcano, the ordinary cooling influences of cold rocks and subterranean waters and air would be sure to bring out, in some degree, on a globe having existing climatal conditions, the characteristics of the several kinds of volcanoes designated.

It cannot be affirmed that this higher heat required for the complete fusion of trachyte or rhyolyte is wanting at convenient depths below; for it has been manifested in the out-

pouring of vast floods of these rocks through opened fissures, many examples of which over the Great Basin are mentioned in King's "Systematic Geology" of the Fortieth Parallel. But in the volcano, whose work, after an initial outflow, is carried forward by periodical ejections, and requires for long periods a continued supply of great heat, the more or less granulated or pasty condition of the outflowing orthoclase-bearing lava-streams is the usual one. Consequently, when a volcano changes its lavas from the less fusible to the more fusible, as sometimes has happened, some change in the features of the volcano should be looked for, except perhaps when the change occurs directly after the initial discharge.

Here the question suggests itself whether the temperature existing at depths below may not be one of the conditions that determine whether the discharged lavas shall be of the less fusible or the more fusible kind.

But a *basalt*-volcano also may fail to have heat enough for perfect fusion, and hence may have partially lapidified or pasty lavas, and thus be made to exhibit some of the characteristics of the other kinds of volcanoes. This condition may result from three causes: (1) A decline in the supply of heat of the conduit, as when the partial or complete extinction of the volcano is approaching; (2) When the lava is discharged by lateral openings or fissures, in which case the lateral duct of lava may not be large enough to resist completely the cooling agencies about it; (3) The sudden entrance of a large body of water into the conduit.

The effects from the *first* of these conditions — declining heat connected with approaching extinction — are strikingly exemplified in two great volcanic mountains of the Hawaiian Islands, Mount Kea on Hawaii, and Haleakala on Maui. Those of the *second*, in which the ejections are from lateral openings, are abundantly illustrated in the cinder and tufa cones of the islands, and also in widespread cinder or ash

deposits through the drifting of the ejected material by the winds. The *third*, a sudden incursion of waters through an opened fissure, if a possibility, should both lower the temperature and produce violent projectile results; and even Kilauea bears evidence of at least one eruption of great magnitude which was thus catastrophically produced, — that of 1789; for the region bordering the crater on all its sides, and to a distance of ten or fifteen miles to the southwest, is covered with the ejected stones or bowlders, scoria, and ashes of such an eruption.

Besides the influence of degree of fusibility of the lavas on the features and action of volcanoes, there is also some effect from their specific gravity, which varies much with the variations in the amount present of either of the iron-bearing minerals augite, hornblende, chrysolite, and some other related species. But little or no importance is attributable to the amount of silica present, or the *acidic* or *basic* character of the feldspar or rock. The distinction of *basic* and *acidic*, of great interest mineralogically and chemically, has in fact little importance in the science of volcanoes, while that of fusibility is fundamental. The most basic of all the feldspars, anorthite, is as little fusible as the most "acidic" of feldspars, orthoclase, and more so than the equally "acidic" albite.[1] It is plain, therefore, that the quality of being *basic* does not explain the fusibility of the lavas. Neither does it explain any other of the physical characteristics on which the peculiarities of the volcano depend.

It is also true that the chrysolite (or olivine), the ultrabasic constituent of the lavas, has little influence on their physical characters except through its high specific gravity, which is about 3·3 to 3·4. The mineral chrysolite is infusible, and cannot *increase* the mobility of the lavas; and there is

[1] In my "Manual of Mineralogy and Petrography," page 436, I point out further that the distinction of *alkali-bearing* and *not alkali-bearing* among the silicates is of much more geological importance than the much used one of *acidic* and *basic*.

commonly not enough of it in the Kilauea rocks to diminish the mobility; for a large part of the lava contains less than five per cent, and much of it less than one per cent. Chrysolite is *ultra-basic;* but this quality has little volcanic importance. It is not the little amount of silica in it that is influential volcanically, but the much iron. The presence of much chrysolite does not even determine the distribution of the lavas of Mount Loa; for, as shown beyond (p. 324), no Hawaiian lavas contain more chrysolite or have higher specific gravity than some of those of recent ejection at the summit of Mount Loa.

Eruptive Characteristics of a Basalt-volcano. — The obvious results of superior mobility and density in lavas are, as in other liquids: —

First, greater velocity on like slopes, and thus an easier flow, with less liability to be impeded by obstructions; a lower minimum angle of flow, and consequently a less angle of slope for the lava-cones.

Secondly, the vapors ascending through the liquid lava encounter comparatively feeble resistance, and hence the expansive force required for escape of bubbles through the lava to the surface is feeble; and so also are the projectile effects due to the explosion of the bubbles. Hence the projected masses commonly go to a small height — it may be but a few yards — and fall back before cooling, instead of reaching to a height that involves their cooling and solidification in the air and the making thus of cooled fragments of lava or scoria, called cinders and volcanic ashes.

The projectile process in the basalt-volcano, as long as it is in its normal stage, makes, as stated on page 17, not cinder-cones, but *driblet-cones*, fifteen to sixty feet high, out of the projected masses, the falling driblets becoming plastered together about the small places of ejection. Among the projectile results of volcanoes driblet-cones are at one extremity of a series, and cinder or tufa cones, many hundreds of feet

high, at the other. A cinder-cone of a thousand feet in height has fifteen to twenty thousand times the bulk of any driblet-cone. The process is one; but the result varies with the mobility and fusibility of the lavas.

Further: in the great lava-cone of a basalt-volcano in its normal stage, cinder or tufa deposits rarely alternate with the large lava-streams, while they commonly alternate in other kinds of volcanoes.

Further: cinder-cones and beds of volcanic ashes may form about a basalt-volcano, as already explained, whenever the condition of insufficient heat is in any way occasioned.

The above views as to the characteristics of a normal basalt-volcano are sustained by the facts from the volcanic mountains of all the Hawaiian Islands.

In the first place, the slopes are not only the lowest possible, usually from less than 1° to 10°, but continuous flows of 10° to 90° occur. The author has seen many of them descending as unbroken streams vertical precipices on southern and western Hawaii. The example shown in Plate XI. is small compared with many about Mount Loa.

Again: the alternation of the lava-streams of the great volcanoes with deposits of volcanic sand, scoria, or stones that were ejected from the great craters, is of rare occurrence; and such deposits make only thin beds of the kind whenever they occur. In such examinations as the author was able to make of the walls of Kilauea and Haleakala and of the precipices and bluffs of Oahu he did not succeed in finding cinder or tufa deposits among the lavas of the body of the mountain, though a common feature wherever lateral cones have been thrown up. The walls of Kilauea are stratified from top to bottom, but with lava-streams, and comparatively thin streams. No evidence was found in the examinations of its walls of any intervening stratum or bed of scoria, tufa, or stones like that which now covers its border. This testimony is not conclusive as to the absence of such projectile

eruptions in former times; for thin beds of scoria or sand like that just referred to — its thickness is only twenty-five to thirty feet — might be fused and annexed to the succeeding lava-flow. But the evidence against *great* tufa-deposits among the Hawaiian lavas, excepting those from lateral ejections, is sufficient.

On the island of Maui no such beds of projectile origin were found in the walls of Haleakala, or in those of Wailuku valley, — the probable crater cavity of western Maui. On Oahu the pitch of the layers of lava along the Manoa and Nuuanu valleys is only 1° to 3°; and in the precipices and bluffs which bound them I saw no layer of tufa. The thick tufa-deposits are confined to the beds of cinder and tufa cones, and these are common.

This point needs investigation; for the existence of even thin tufa-beds in alternation with the lava-beds of the great volcanoes of the islands may still be true, and such facts would have much interest. The author observed beds of conglomerate on Oahu and Kaui, but all may have come from lateral cones.

The Crater of a Basalt-volcano is the same in Origin, History, and Functions as those of Volcanoes of other Kinds, but differs usually in Form. — The crater of a great volcano probably has always its beginning in a great discharging fissure, or in the crossing of two fissures; and it continues open until a temporary or final decline of volcanic action, whatever the kind of volcano. It continues open, (1) because of the fixed position of the lava-column, (2) because of the conduit-work going on through it in the discharge of vapors and lavas, and (3) because of the down-plunges in the crater consequent on the undermining which the discharge of the conduit occasions. The open end of a deep-reaching lava-column determines thus, by its discharges and the subsequent underminings, the existence of the crater; and the crater, by the work done within and about it, makes the volcanic cone.

This appears to be the order of rank or importance in the phenomena, — the crater begins in the opened fissure, and is the indicator and future builder of the cone. In the history of the volcano the era of summit outflows may pass, and only lateral discharges take place ; and still the discharge of vapors from the lava-conduit and the accompanying movements in the lavas, together with the down-plunges in the crater following the discharges, will keep the crater or portions of it in continued existence, and the work of eruption or outflow, if subaerial, will be still adding to and shaping the cone.

This is the present stage of Kilauea and Mount Loa ; and these are the results as they exemplify them. The action, functions, and processes are the same whether the lavas fill up to the summit before outflowing, or become discharged at a lower level by an opened fissure.

Examples in the Hawaiian Islands teach also that volcanoes may end with an open crater over two thousand feet deep, like Haleakala, a cone ten thousand feet high, or with a filled crater, as in the case of Mount Kea, thirteen thousand eight hundred feet high.

The preceding remarks about the permanence of craters apply to other kinds of volcanoes as well as the basaltic ; but in the form of the crater the basalt-volcano has peculiarities, owing to the mobility of the lavas and the paucity of cinder discharges. The ordinary crater of the basalt-volcano is pit-like, with the walls often nearly vertical, and the floor may be a great nearly level plane of solid lavas. The liquid material of the extremity of a conduit works outward from the hotter centre, through the fusing heat and the boiling and other caldron-like movements ; and hence, where the mobility favors freedom of action in these respects, it tends to give the basin or crater a nearly circular form, with steep sides. Besides, when the discharge takes place there is usually a fall of the walls, which is still another reason for vertical sides and the pit-like form.

The small lava-lakes of Kilauea, and the Great South Lake also, after a discharge (or an eruption, as it is usually called), are literally pit-craters. Such was the condition of the Great Lake after the eruption of 1886. They all illustrate how the great pit-crater, Kilauea, was made. The "lower pits" of 1823, 1833, 1840, are other examples.

Such pit-craters are normally circular; but where there is a large fissure beneath the crater they may be much elongated.

From the considerations which have been presented we see why the volcanic mountains of the Hawaiian Islands, with slopes rarely exceeding 10° in angle, differ so widely from the great andesyte cones of western North America, with their high slopes of 28° to 35°. We see that the fact of being basalt-made means much in a volcano; that it affects profoundly all the movements and the results of those movements, as well as the shapes of the mountains and of their craters.

2. Size of the Kilauea Lava-column.

To appreciate the power at work in Kilauea and understand its action, we should know, if possible, the diameter of the lava-column beneath; and for this we have to look to its condition both in times of eruption and in periods of relative quiet.

In view of the greatness of the discharge in 1823, — so undermining, owing to its extent, as to drop abruptly to a depth of some hundreds of feet the floor of the crater, leaving only a narrow shelf along the sides, — we reasonably conclude that at that time the lava-column beneath the floor was of as large area as the Kilauea pit itself, — or nearly seven and a half miles in circuit. We may also infer that, immediately before the discharge, wherever there was a lava-lake, the liquid top of the column was up to the floor of the crater, and elsewhere not far below it. The inference is sim-

ilar from the eruptions of 1832 and 1840. When the floor of the pit fell at the discharge in 1840 it was not thrown into hills and ridges, as it might have been had it dropped down its four hundred feet to solid rock in consequence of a *lateral* discharge of the lavas beneath; on the contrary, it kept its flat surface, thus showing that it probably followed down a liquid mass, that of the subsiding column of lava.

But it is probable that the conduit had then, and has still, a larger area than that of the Kilauea crater.

At the eruption of March, 1886, when the emptying of Halema'uma'u and its bordering lake at the south end of Kilauea was all the visible evidence of discharge, the solfatara at the north end, two and a half miles from Halema'ma'u, showed sympathy with the movement; for the escape of vapors from its fissures suddenly ceased, as if the *source* of the hot vapors had participated in the ebb, while a few hours before the discharge the vapors were unusually hot, so as to prevent the use of the bath-house. Thus, even now, during a comparatively small discharge, we have evidence that the two distant extremities of the crater are underlaid by intercommunicating liquid lava. Mr. Brigham speaks of hearing in 1880, when at the vapor bath-house in the solfatara, sounds from below, — "rumbling and hard noises, totally unlike the soft hissing or sputtering of steam," [1] — a fact that seems to favor the above conclusion. Further, through all known time, as now, several of the fissures in the solfatara region have discharged, besides steam, sulphurous acid freely; and this is probably from liquid lavas.

The summit of the conduit must, therefore, be even larger than all Kilauea. To this may perhaps be added the bordering region of fissures and abrupt subsidences; for subsidences or down-plunges indicate undermining; and undermining here means the removal of liquid material from beneath. With this addition to the limits, the width is sixteen thou-

[1] American Journal of Science, 1887, xxxiv. 27.

sand feet, and the length as much, *plus* a mile or more to the southwest, where the fissures of 1868, if not also of earlier date, are giving off hot vapors abundantly.

But while this may be the area of the upper extremity of the lava-column, its top surface is not a level plane, as the condition of the region over it indicates. A small part of it at all times (with short exceptions after an eruption) has extended up to the surface in Halema'uma'u, and occasionally in other lava-lakes during times of special activity; for each such lake, however small, must have its separate conduit reaching down to the general liquid mass and giving upward passage to the working vapors. We learn, hence, that whatever the number of these large and small conduits, they may act — that is, overflow, and rise and fall in level — independently, because the size is very small compared with that of the reservoir from which they rise.

3. Ordinary Work of Kilauea.

By the ordinary work of Kilauea is here meant the work which is carried on between epochs of eruption. A large part of it is the living work of the volcano, the regular daily action, never permanently ceasing except with the decline and extinction or withdrawal of the fires. The deep-reaching column of lavas, which is the source of the heat and centre of this living activity, owes a large part of its power to act the volcano, and make a volcanic mountain, to the presence of something besides heat and rocks. Vapors are ever rising and escaping from the conduit, and though lazy in the clouds above where their work has come to an end, they carry on nearly all the *ordinary* action of a crater, even that of greatest brilliancy and loftiest fiery projection, as well as the gentler play of the fires. But these vapors have not produced the great eruptions in Kilauea since the century begun; they occasion only its

quiet or lively activity in periods of regular work between eruptions. I add also, lest I be misunderstood, that the vapors are bad for fuel, as they tend to put the fires out, but good for work.

There is another source of work, perhaps a perpetual source during the active life of a volcano as it is a perpetual source of heat; namely, the ascensive force of the conduit lavas. But, unlike the vapors, it is an invisible agency, slow in its irresistible movements. What are its limitations, and what its source, still remain undetermined.

The other agencies concerned in the ordinary work have only occasional effects. They include heat in work outside of the conduit, and hydrostatic and other working methods of gravitational pressure.

Tabulating the agencies, they are as follows: —

A. The vapors.
B. The ascensive force of the conduit lavas.
C. Heat, displacing, disrupting, fusing.
D. Hydrostatic and other gravitational pressure.

All these agencies do their work around the lava-conduit, as their central source of energy, or about its branches, and therefore, as has been explained, pericentrically.

A. THE WORK DONE BY VAPORS.

Only part of the work of vapors is of the permanent kind, carried on, as above described, by the vapors rising through the lavas of the conduit. Another efficient part, but most efficient in times of eruption, is dependent on vapors generated outside of the conduit. In addition, there are the chemical effects of vapors. The work includes: —

1. The effects of the expansive force of vapors in their escape from the liquid lavas: projectile action and its results.

2. The effects of the expansive force of vapors within the liquid lavas: vesiculation and its results.

3. The effects of vapors generated outside of the conduit: fractures, displacements, etc.

4. The chemical action of vapors; which is considered in this work only as regards certain metamorphic effects.

1. The Vapors concerned: their Kinds and Sources.

The vapors of Kilauea have not yet been made a subject of special investigation. Still, there is no question that the chief *working* vapor is the vapor of water; besides which there is a little sulphur gas, and probably some atmospheric air. Investigations elsewhere have established the fact of the vast predominance of water-vapor among aerial volcanic products, proving that less than one part in one hundred is vapor of any other kind. The statement of Mr. J. S. Emerson[1] that on the west margin of Halema'uma'u, at one of his surveying stations in April of 1886, to leeward of a "smoke-jet," he continued his work "without regard to the smoke which the wind carried over him within a few feet of his head," is proof that the air held little sulphurous acid.

Mr. Brigham was led to conclude, from his seeing so little vapor rising from the Great Lake during his visit, that too much influence had been ascribed by others to water; and this view is presented also by Mr. W. L. Green. of Honolulu, who refers part of the movements in the lake to escaping atmospheric air; the air being supposed to be carried down by the splashing and jetting lavas, there to become the source of the splashing, and to become confined in this and other ways, and be carried deeper for other work.[2] But the amount of vapor escaping from a lake in times of moderate activity, when it is mostly crusted over, is very small, being only that from the vesicles (p. 166) and breaking bubbles in the actively liquid portion; and in

[1] American Journal of Science, 1887, xxxiii. 90.

[2] Vestiges of the Molten Globe, part ii., 8vo, Honolulu, 1887.

a state of brilliant action, the hot air above, up to a height where the temperature is diminished from that of the liquid lavas to 300° F., will dissolve and hold invisible nearly five times as much moisture as at 212°; up to 440°, sixteen times as much; and to 446°, twenty-seven times. The absence of vapors over a flowing lava-stream is made evidence against the presence of water; but if all is from one source, *there should be none* except at the source.

The amount of sulphur in the vapors, and its condition before the escape from the lava, whether as sulphur vapor simply or as sulphurous acid (sulphur dioxide), are questions for the future investigator. Pyrite, or some iron sulphide, being its probable source, I add that I have detected pyrite in the lava of a dike on Oahu, but not in the lavas of the crater, where we should hardly expect its presence. Chalcopyrite (copper pyrites) may also be present, as stated on page 73. The faintly greenish tint of the flames mentioned on pages 88, 96, 119, may have this source.

Carbonic acid has not been observed escaping from fumaroles about any part of the Hawaiian Islands, and no fragments of limestone have been found among the ejectamenta of Kilauea or Mount Loa. The volcanoes stand in the deep ocean, and the conduit must come up through old lavas for thousands of feet, and hence carbonic acid is only a possible not a probable product. The position of the volcanic region in mid-ocean, where continental geological work has most probably never gone forward, makes it almost certain that there is none above the level of the ocean's bottom.

The presence of *hydrogen* among the escaping vapors remains to be determined. The pale flames seen about the Great Lake may come from the burning of escaping hydrogen or of sulphur vapor or of hydrogen sulphide.

The *source of the water or moisture*, whence comes the chief part of the escaping vapors, is probably atmospheric.

On this point the arguments appear to be as strong now as in 1840.

Kilauea is situated, like Hilo, in a region of almost daily mists or rains, and if approaching Hilo in amount of precipitation, as is probable, over one hundred inches of rain fall a year. Tables give over two hundred inches some years for Hilo. The whole becomes subterranean, except what is lost by evaporation; for, owing to the cavernous and fissured rocks, there are no running streams over the eastern or southeastern slopes of the island south of the Wailuku River, which comes down from the northwest to Hilo. That which falls into Kilauea and on its borders gives moisture to the many steaming fissures; and sometimes it makes a steaming area of the whole. But this part has very little to do with the volcanic action.

Part of the subterranean water follows the underground slopes seaward, as shown by copious springs in some places near the shores, and takes no part ordinarily in the volcanic work. But another part must descend by gravity vertically, or nearly so, and keep on the descent far below the sea-level. It has been shown on a former page (p. 125) that much the greater number of the eruptions have occurred in the months from March to June, and this appears to indicate a dependence of the action to some extent on the abundance of precipitation.[1]

Moisture may be gathered also from all moist rocks along the course of the conduit in the depths miles below the reach of superficial waters, as suggested by different writers on volcanoes. But any dependence on the amount of precipitation would show that this is not its chief source.

Another source of water is the sea. But sea-water could

[1] This view with regard to the sources of the waters is sustained by several writers. It is well presented, with explanations at length as to the water-line in the volcanic mountains, in a paper on "The Agency of Water in Volcanic Eruptions," by Prof. Joseph Prestwich, Proceedings of the Royal Society, xli. 117.

not ordinarily gain access to the lava-column except at depths much below the sea-level, on account of the abundance of subterranean island waters pressing downward and outward. Further, no one has yet reported evidence of the presence of marine salts, or chlorides, beyond mere traces, among the saline products of Kilauea or Mount Loa after an eruption.

A third source of moisture is the deep-seated region in or beneath the crust whence the lavas come. Of this we know nothing. The fact that the presence of such moisture below would make this a dangerous earth to live on has been urged against the idea of such a source.

Since all ordinary action in Kilauea, and also in Mount Loa, is of the quiet non-seismic kind, the introduction of water into the conduit must be an ordinary and a quiet process, not one of sudden intrusion through fissures. Sudden intrusions may sometimes take place for eruptive effects, but of these we are not speaking. The facts from the vesiculation of some lava-flows of Mount Loa, brought out beyond (p. 166), give further evidence as to the quiet molecular occlusion of the waters. Moreover, as remarked on page 19, the possibility of this method of imbibition appears to be demonstrated by Daubrée's experimental work, which proves that the process will go on through capillarity or molecular movement, against the opposing pressure of vapors within.[1] He uses the fact to explain the origin of volcanic vapors.

2. The Effect of the Expansive Force of Vapors in their Escape from the Liquid Lavas : Projectile Action.

All the lava-lakes of the crater, whether one alone exists or many, and the smaller vents over fires that are concealed

[1] Géologie Expérimentale, 2 vols. 8vo, Paris, 1879, p. 235.

The temperature of the liquid lava is nearly that of the dissociation temperature of water — 1985° F. to 2370° F., according to M. H. St. Claire Deville, — and higher than this no doubt at depths below. But that dissociation takes place within the conduit, under the pressure there existing, is not satisfactorily proved.

but not at too great depths, send forth vapors, which in their effort to escape as bubbles through a resisting medium, that is, the lavas, do projectile work. The vapors thus produce the play of jets over lava-lakes with the muffled sounds and tremor of ebullition ; and also the splashing and the throwing of spray from open fire-places along the borders of the crusted lakes. They dash up the melted fragments from a blow-hole with a rush and roar "rivalling sometimes a thousand engines," thus introducing the coarser effects of gunnery into Kilauea. They make the thin crust of the crusted lake to heave and break, press into rope-like folds the lava along the red fissures, or start a new play of fiery jets, high or low, and frequently several in alternate play; or they make openings and push out a flood of lava ; and occasionally, when rising in unwonted volume, they make lava-fountains of unusual heights over the lakes, with at times loud detonations.

The projectile force required to throw up jets of lava to the height which they ordinarily have in times of brilliant activity, thirty feet or so, is even less than a calculation from the height, diameter, and density would make it, because the jets before they reach their limit usually have become divided into clots, instead of remaining a continuous stream.

The fact that the throw in the projectile action of a crater is usually vertical is well shown in some of the vertically columnar forms of driblet-cones. This is the case in that of the figures on pages 71, 91, in which the column was elongated vertically, although a result of successively descending drops. This vertical throw — due to the fact that the top of the bubble is the weak, and therefore the exploding, spot — makes the projectile action *good for throwing upward, but not good for a destructive bombardment of a crater's walls.*

Common observations would lead us to expect that in a low state of the fires, when the large lake is for the most

part thinly crusted over, the point of greatest heat and action would be toward the centre; instead of this, it is usually at the margin, and often in oven-like places partly under the cover of the border rocks. The only explanation that now appears is that already given, — that along the border, under cover, the outside cold, or that of the atmosphere, is much less felt than over the central portion.

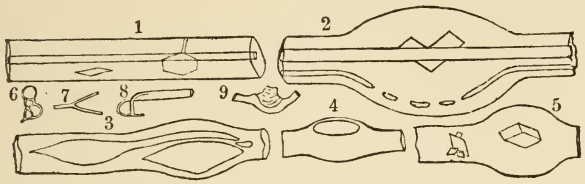
One of the *secondary results* over the floor of the crater of the projectile work is the making of the fantastic *driblet-cones*, formed often about blow-holes out of the descending clots and drops and worming streamlets, as already explained. Occasionally the particles of the projected lava are small and descend in small showers of loose, smooth-faced, but variously shaped bullets and granules around the vent; and this is the nearest the crater at present comes toward producing cinder-cones.

Besides making driblet-cones, the projectile work raises somewhat the borders of the lakes. Further, the small overflows, lapping in succession over the borders, often make them steep, and keep increasing their height until a heavier outflow sweeps one side or another away.

A third incidental result of the projectile action is the making of *capillary glass*, or *Pele's hair*, from the glassy part of the lavas. In the jetting and splashing of the lavas the flying clots and drops pull out the glass into hairs, — just as takes place in the drawing apart of a glass rod when it is melted at middle. Mr. Brigham says that "the drops of lava thrown up draw after them the glass thread, or sometimes two drops spin out a thread a yard long between them." His new observations of 1880[1] accord with this explanation, but are remarkable for the length and size of Pele's tresses reported as hanging from the roofs of the fiery recesses.

[1] American Journal of Science, 1887, xxxiv. 22.

The microscopic structure of the capillary glass has been studied with care by C. Fr. W. Krukenberg.[1] In his fifty figures, a few of which are here copied, the glassy fibres are sometimes forked or branching, sometimes welded at crossings, and often contain air-vesicles (3, 4) and microscopic



Pele's Hair.

crystals (1, 2, 5), often tubular (1, 2) through the drawing out of a minute air-vesicle. They also show that the air-vesicles sometimes continued expanding as the glass was drawn out, and that the hair is often enlarged about enclosed crystals. The crystals are rhombic, as in the figures. The facts make it evident that the glass is far from being pure glass.

3. The Effects of the Expansive Force of Vapors within the Lavas. — Vesiculation and its Mechanical Effects.

Origin. — Vesiculation, the making of bubble-like cavities in a melted rock, is a noiseless unseen effect of the vapors that are rising and expanding *within* the lavas. The expansion necessary to produce them is resisted by the cohesion in the lava and by the pressure. Consequently it is a very common feature of the easily fusible volcanic rock basalt, but not of trachyte or rhyolyte, except in pumice, the glassy scoria of these rocks ; and even this glass (obsidian) commonly holds to its moisture, if it contains any, without vesiculating.

Owing to superincumbent pressure, the maximum depth of vesicles is small, as has long been recognized ; but how

[1] Micrographie der Glasbasalte vom Hawaii ; petrographische Untersuchung, 38 pp. 8vo, with 4 plates, Tübingen, 1877.

small in basalt or any other rock, has not been ascertained by experiment. It probably does not occur in the Hawaiian Islands below a depth of a hundred feet. Above the lower limit vesicles may increase in number and size toward the surface, and be largest in the scum or crust, as within Kilauea; but this variation upward is not always a fact.

Kinds. — Five styles of vesiculation may be distinguished in the Kilauea ejections, two of which characterize stony lavas, and three scorias.

1. That of the ordinary lava-stream of the floor of the pit. The vesicles are oblong and of irregular shape, and constitute from less than one to fifty or sixty per cent of the mass of the rock. The form is spherical when the vesicles are very few and small.

2. That of the common stony *spherically vesiculated* lava. The vesicles make thirty to sixty per cent of the mass, and are too small to be elongated much by the flow. This kind of lava occurs in streams outside of Kilauea, and in many about the slopes of Mount Loa.

The best example of it I have seen, and the basis of the following description, is that of the 1880–1881 Mount Loa flow, near Hilo. The small uniformly crowded vesicles constitute about forty per cent of the mass. They characterize the lava, with scarcely any change in size and numbers, to a depth (as I found in a tunnel within the lava-stream whose floor was similar) of ten or twelve feet. Below this depth of ten or twelve feet the lava, as I learned from Rev. E. P. Baker of Hilo, is probably more solid, this being usually the case.

The scoriaceous kinds are —

3. That of the glassy scoriaceous crust of the lava-stream inside of Kilauea, and of the scum of its lava-lakes (p. 70). The vesicles are sixty-five to seventy-five per cent of the mass; they are elongated, those at top mostly closed, those of the bottom of the crust commonly very large. The half-

solid crust of the lake is sometimes so thin that stones thrown on it slump through. The glass is easily fusible, and hence its rapid fusion and cooling. An analysis of this scoria-crust by Prof. O. D. Allen proved it to have the composition of ordinary basalt.[1] No analysis has been made of the stony lava of Kilauea for comparison.

4. Ordinary scoria, such as is common about cinder-cones outside of the crater, mostly stony in texture; the vesicles sixty-five to ninety-five per cent of the mass.

5. Spongy *thread-lace* glassy scoria, occurring as a layer twelve to sixteen inches thick over the southwestern border of Kilauea, as stated on page 44; the vesicles ninety-eight to ninety-nine per cent of the mass; their walls in the coarser varieties sieve-like or reticulated, in the finer like thread-lace in texture. Similar spongy scoria is reported as occurring at the summit of Mount Loa and about the sources of some of the Mount Loa lava-flows.

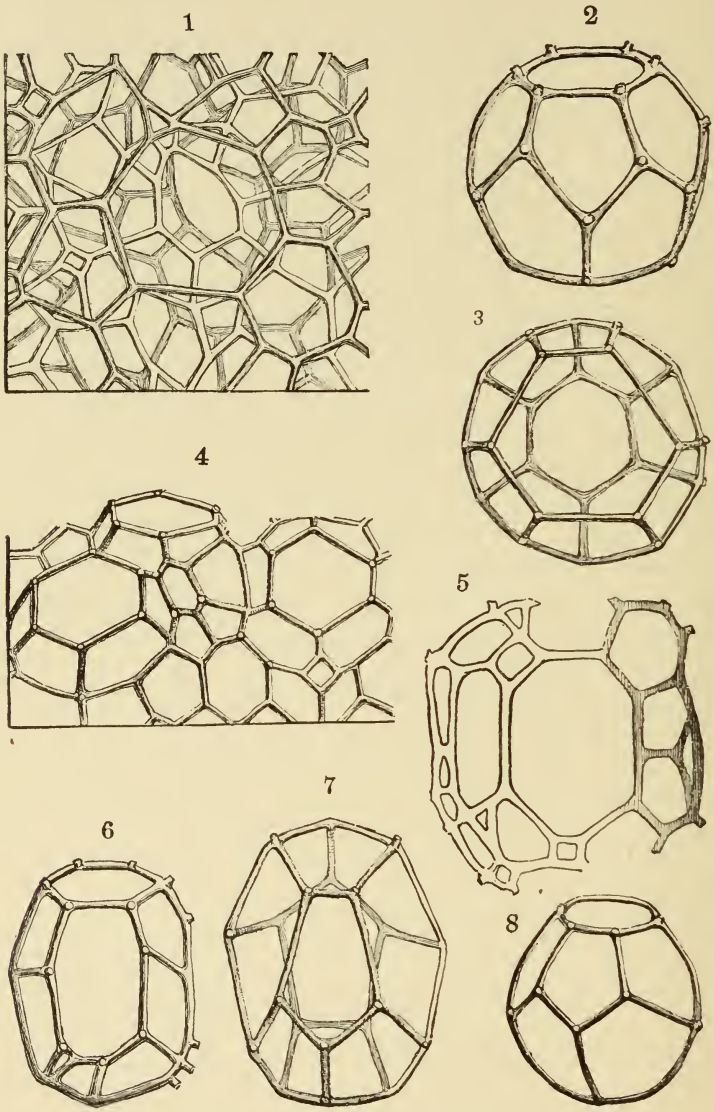
Since a cubic inch of the finer thread-lace scoria contains only 1·7 per cent in bulk of rock material, a layer of solid basalt glass one inch thick would be sufficient to make a sixty-inch layer of the spongy material, and probably a seventy-five to a hundred inch layer of the much more common coarser variety, in which are some large vesicles occasionally half a cubic inch in size.

[1] Professor Allen's analysis (American Journal of Science, 1879, 3d series, xviii. 134) is in column A, below. For comparison the composition is added of (B) the doleryte (diabase) of West Rock, New Haven, Conn., of Triassic age, by Mr. G. W. Hawes (Ibid., 1875, ix. 186), and of (C) a "typical" basalt from Buffalo Peak, east of the west fork of the Platte, between the two Parks, by R. W. Woodward (Descriptive Geology, "Geology of the Fortieth Parallel," 1877, ii. 126).

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	ign.	P_2O_5	
A	50.75	16.54	2.10	7.88	*trace*	7.65	11.96	2.13	0.56	0.35	----	= 99.92
B	51.80	14.21	3.55	8.26	0.42	7.63	10.68	2.15	0.39	0.63	0.14	= 99.86
C	49.04	18.11	2.71	7.70	*trace*	4.72	7.11	4.22	2.11	1.29	TiO_2 2.46	= 99.47

I add that I do not cite here the analyses of the rocks and volcanic glass of Kilauea made by another for me and published in my "Expedition Report," because they are erroneous and should be rejected.

The vesicles of the finest kind are mostly one thirtieth to one fortieth of an inch in diameter, like those of the 1880–



Cells of the Thread-lace Scoria.

1881 Mount Loa flow; but their walls are reduced to threads corresponding to the edges of polygonal vesicles. Fig. 1 shows the general appearance of the surface in a magnified

view. The forms of the skeleton polygonal cells are for the most part either twelve-sided or fourteen-sided figures, having a perimeter of ten or twelve pentagonal faces in two alternating rows, and bases of five or six sides. The twelve-sided cells are bounded by the edges of pentagonal dodecahedrons such as come from the mutual pressure of spheres, except that they are distorted usually by compression and by elongation or abbreviation. The fourteen-sided, which are much the most common, are similar to the twelve-sided in general form, but have hexagonal bases. Fig. 2 is a side view and Fig. 3 an end view of one of the latter kind, and Fig. 4 shows a group of such cells as seen over the surface of the scoria (a cut or broken surface, for it is impossible to handle a piece of the scoria without breaking off bits of the brittle threads). Fig. 6 is another of the fourteen-sided kind of less symmetrical form, as is common. One of the pentagonal dodecahedrons is shown in Fig. 7, and another in Fig. 8.

There is often a more complex system of network through other crossing contour-threads, but the simpler forms are referable to those represented. The inside of the base of one of the large and therefore less regular forms is shown in Fig. 5; the diameter was about one twentieth of an inch. In the largest vesicles the walls are openly reticulated.

The threads of this thread-lace scoria are not rounded, but parts of the contours of the three elliptical cells that were there in contact; and Fig. 9 shows a portion of one. Having this form, the glassy material of the threads is thickest, and therefore of darkest color, at the centre; and they are still thicker and darker at the angles or junctions of three threads. This glassy scoria calls to mind the vesiculation of an obsidian by a high heat, converting it into pumice or scoria because of its occluded water, as illustrated

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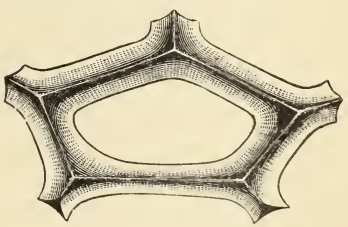


by Professor Judd, and also by Mr. Iddings in experiments with the obsidian of the Yellowstone Park. The Kilauea glass must have been penetrated molecularly with water to have produced such a result. Its ejection took place after the violent projection of great stones, — and apparently not long after, as it overlies directly the layer of stones.

The minute delicacy and brittleness of the threads in this scoria suggest a way of making fine dust by volcanic action, which is much more reasonable than that of mutual friction of projected fragments of scoria of the ordinary kind; it thus helps in the understanding of the lofty dust-clouds of Krakatoa and Tarawera.

Amount of Moisture required for Vesiculation, its Distribution, and its Origin. — The facts derived from the crowdedly vesiculated lava of 1880–1881, reaching from its source down to Hilo, over thirty miles, and throughout the whole range remarkable for uniformity and for depth in the stream, besides giving an opportunity to study the origin of the vesiculation and the amount of moisture it requires, presents also evidence as to the origin of the moisture in the conduit and its condition.

1. According to the report of Rev. E. P. Baker, the vesicles change little toward the summit except in becoming coarser, with thinner walls, at the source. From the mean size, one thirty-fifth of an inch in diameter, we obtain for the *size of the particle of moisture* required at the ordinary pressure to fill one of the vesicles, ·000,000,007 of a cubic inch. What the size actually was, under the pressure and the temperature that existed at the time of vesiculation, cannot be determined. But this much we learn, that the moisture was distributed throughout the lava in a state of extreme division, actually or essentially that of molecular diffusion.

2. The space in the vesicles is forty per cent of the mass, as determined from the specific gravity of the rock-material,

2·98, and that of the mass with the surface varnished to exclude the water, 1·88. The required water is hence ·0003 per cent of the mass, or by weight ·0001 per cent; showing that *the amount of water required for the vesiculation is exceedingly small.*

From the thread-lace scoria we find, since only 1·7 per cent of the mass is solid glass, that the amount of moisture required to produce the vesiculation, at the ordinary pressure, would be 3·125 per cent of bulk, and 1·1 per cent by weight. The amount of moisture was hence not unusual for a rock, although the vesicles occupied 98·3 per cent of the mass.

3. The source of the flow of 1880, 1881, according to Mr. Baker, was about 11,100 feet above the sea-level. This is 2,575 feet below the summit of Mount Loa, or about 1,600 feet below the bottom of the summit crater. Before the outbreak the liquid lavas were active within the crater; that is, the length of the conduit above the place of outbreak was then about 1,800 feet. On account of the pressure of 1,800 feet of liquid lava no vesiculation could have taken place at this depth inside of the conduit; but at the discharge the lavas escaped from the pressure, and the vesiculation by means of the diffused moisture must have then begun. Whether the vesiculation for the whole stream took place at or near the source cannot be decided without more knowledge of the flow and its actual sources than we now have.

4. The facts also tend to sustain the conclusion, before expressed, that the ingress of the subterranean waters, whatever their source, took place by molecular absorption; for it produced an essentially equable molecular distribution.

The Distribution and Functions of Moisture after reception into the Conduit. — 1. The above conclusions from the vesiculation have prepared the way for additional deductions as to the distribution and movements of the moisture in the conduit. After its reception it is exposed to a heat at least

1500° F. beyond the critical point of water (773° F.), and retains the temperature of fusion to the surface. If the expansive force has at the ingress under the pressure any effective value, the accession of the moisture will diminish somewhat the density of the lava, that is, increase its bulk; and this increase will be greatest along the central region of the conduit, because this is the region of greatest heat. If dissociation takes place the increase is still greater, as it adds to the bulk of the moisture. It is a question, therefore, whether the pressure of the denser *lateral* lavas of the conduit would not have some effect toward producing an upward movement along the hotter central region.

2. The mechanism of the volcano, as regards these inside vapors, seems then to be this: (*a*) a molecular absorption, at depths below, of subterranean waters from regions either side; (*b*) a rise of the lavas, thus supplied with moisture, along the conduit from some cause (see beyond on "the ascensive force of the conduit lavas"), and perhaps partly in consequence of the vapors present; (*c*) after reaching a level where the pressure is sufficiently diminished, a union of the molecules of water into gas-particles, *producing* by their expansive force *vesiculation;* (*d*) a further union of particles into bubbles, when the vapors are sufficiently abundant, in order to exert the greater expansive force required to escape through the surface of the lavas, *producing projectile results.*

Mechanical Effects of Vesiculation. — Vesiculation tends in a quiet way to increase bulk, as the above-mentioned facts illustrate. It therefore will give increased height to the liquid lava in a conduit. How deep down this effect is appreciable is a point of much importance in its bearing on the movements and levels of the lavas of conduits. If only to a depth of two hundred feet, an average of twenty per cent of vesicles would add only forty feet to the height or level of the surface.

But if the vapor particles at all deeper depths are, through

their expansive force, undergoing gradual expansion as they work their way or are carried upward, we are still further in the dark as to the amount of effect of vapors on the bulk of the lavas in a conduit. After the author's observations of 1840, he was led to question, as is stated in his "Expedition Report," whether the effects from this means might not be sufficient to account for much of the excess of elongation of the Mount Loa column over that of Kilauea. This is obviously not so. But how much the elongation is, is an important question, and it has still to remain unanswered.

4. Work of Vapors generated outside of the Conduit: Fractures, Displacements, and other Results.

The conduit has hot rocks around it; and beneath the floor of the crater there are hot rocks about and over its upper extremity. The descending waters are driven back as vapor, and usually in a harmless manner. But a sudden incursion of subterranean waters happening under any circumstances, might produce confined vapors of great amount and force. The natural effects of the pressure of such confined vapors are fractures, elevations, and subsidences, and, where pressure is brought to bear in a confined place on a source of liquid lavas, their injection into any open fissure at hand.

These effects belong mostly to times of eruption; but in a lighter form they may be part of the ordinary work of the crater. The lava-lakes of the bottom, even in quiet times, often have large overflows, and also outflows through fissures, that is, both *superfluent* and *effluent* discharges; and it is probable that the cause here considered may be the occasion of part of them.

Confined vapors are often generated also by the action of the heat of a lava-flow on moisture underneath it. As rains fall almost every day at Kilauea, there must be more or less moisture underneath many parts of the cold floor; and if a few hours' flow from the great lake should flood it with

liquid rock, its 2000° F., which the bottom of the stream carries along and does not at once lose, would make vapor out of the moisture, having great expansive force. The large dome-shaped bulgings of the lava-streams and other undulations of the surface may thus be accounted for; and many of the steaming fractures of the floor as well as those of the domes may have the same origin.

B. THE ASCENSIVE ACTION IN THE LAVA-COLUMN.

Evidence. — The evidence in favor of an uplifting action by the ascensive force has been presented on pages 76, 109. It is briefly as follows: —

1. The observations in 1846 by Mr. Chester Lyman demonstrate that in six years the lower pit of 1840, averaging ten thousand feet by twenty-five hundred in its diameters and nearly four hundred feet in depth, had gradually become obliterated, and chiefly through an uplift of the floor; for the floor bore on its surface the talus of lava-blocks that had fallen from the walls. Overflows had done part of the work, but "subterranean force," as Mr. Lyman concluded, the larger part. Mr. Coan, who was with Mr. Lyman at the time, appreciated the evidence, and later described the lifting as "not uniform in all parts; as sometimes taking place here and there abruptly; but as producing nearly uniform results, except a greater rise toward Halema'uma'u."

2. In 1868 Mr. Brigham gave further evidence as to the Lyman ridge by the representation of what remained of it in 1865 on his valuable map, though not, as his memoir shows, understanding its origin. Besides this the painting of the crater of about the same date (1864 or earlier) by Mr. Perry (p. 87), afforded confirmatory proof as to its position and extent at that time.

3. In 1848 Mr. Coan observed that a cone of broken lava, that had formed within the Halema'uma'u basin, was lifted

by "subterranean action," as he argued, because only slight additions were made to its outside by ejections. It continued to rise bodily until it was as high as the near walls of Kilauea. Between 1880 and 1882 another debris cone began in the basin of Halema'uma'u, which, as he describes, rose in like manner without additions to its summit, and finally became two hundred feet or more high; this cone continued to exist until the eruption of 1886.

The subterranean force appealed to was plainly force arising in some way from the lavas beneath. Mr. Coan, in his letters, supposed that the lifting was produced by the injection of the lavas of the conduit into open spaces between the solid layers below.

4. Again, in the summer of 1886, three months after the eruption of that year, the debris from the fallen and falling walls of Halema'uma'u were made into a cone occupying a large part of the interior of the basin; and from August onward, it was apparent that the cone so made was slowly rising, though having little outside additions; in October of 1886, its top was on a level with the rim of the basin; in January, two hundred feet higher, so as nearly to overtop the southeastern Kilauea walls. It was early apparent to visitors at the crater that the elevation was through action below; and soon the conclusion was general, among observers, that the cone, as expressed in the words of Mr. Dodge, of Jan. 14, 1887, was "rising slowly as though floating on the surface of the new lava-lake."[1]

[1] American Journal of Science, xxxiv. 70. When at Honolulu, Mr. Parmelee, of that place, informed the author that in August of 1886 he made observations on the rate of change of level, by sighting from the Volcano House veranda over a post one hundred yards in front of the house, and marking the change of the line of sight on a pillar of the veranda. His observations were made between the 19th and 21st of the month. On the first day the rise, according to his calculated result, was sixteen feet; on the second, seventeen feet; and on the third, eight feet. These numbers are large. They were not verified by observations near the cone. They at least prove progress in the elevation.

The ascensive force was thus proved to be great, and its effects to have fundamental significance.

Method of Action. — It is a question whether, in the lift of the floor of the great crater in 1823, 1832, 1840, 1868, the lavas of the lava-conduit acted by direct thrust, or through injections into spaces between the layers of solidified lava beneath it.[1] The facts favor strongly the former of these views. In the first place, the lateral thrust in the upper lavas of a conduit is necessarily feeble; for the conduit there, or near by, opens to the surface. Then, secondly, it is quite certain that the breadth of the Kilauea conduit at top has been, at the times of these uplifts of the floor, large enough to act somewhat equably against the floor. Thirdly, since the floor kept its even surface as it fell at the great eruption of 1840, it must have followed down, as already urged, the subsiding lavas. The flotation method, or that by direct thrust, seems therefore to be the right one. It is the obvious explanation of the lifting of the debris cones of Halema'uma'u.

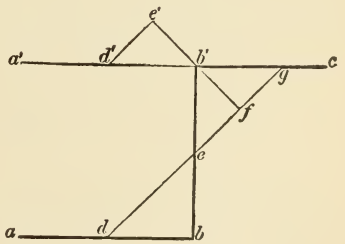
Kilauea affords, as has been indicated, facts illustrating the details connected with the lifting movement.

Fault-planes of the up-and-down Movements about the Pit. — (1) The down-plunge of 1823, 1832, and 1840 left, for the most part, vertical walls bounding the "lower pit" so made. There is evidence that these were fault-walls; that is, planes of fracture with a vertical displacement along them equal to their height, or about four hundred feet in 1840 and six or eight hundred feet in 1823. In the reverse movement — that is, the rise after the down-plunge of 1840 — the old floor was carried up along the same fault-planes. The rate of rise, as shown on page 16, was seventy to one hundred and thirty feet a year, which is to be divided between (*a*) overflows, (*b*) vesiculation if this had any effect, and (*c*) ascensive force apart from vesiculation.

[1] The latter is the explanation adopted by Mr. Brigham in his paper of July, 1887, American Journal of Science, xxxiv. 19.

Further: these vertical fault-planes of 1840, and others subordinate to them along the border regions, appear to have determined the chief places of eruption — that is, of lava-lakes, cones, ovens, and opened fissures — in Kilauea *during the next thirty years*. They were plainly the occasion of the wonderful girt of fires, four miles long and half a mile wide, which was three times repeated after the year 1846 before the eruption of 1868 (in 1855, 1863, and 1866), while the interior plateau suffered relatively little change from erupting forces, and in some parts was growing ohelo bushes and ferns.

The position of the "canal" in Kilauea in 1846, described by Mr. Coan and also by Mr. Lyman as extending around the crater, bounded by the outline of the old black ledge and the Lyman ridge of lava-blocks, and which became gradually filled by inflowing lavas and debris, has here its explanation. The circumferential fault-planes of the pit of 1840 coincided with the face of the lower wall or precipice. The debris which fell from the wall necessarily fell to the floor beyond the plane, and there began the making of the talus. Through the fall of the face of the wall, the wall, and thereby the limit of the black ledge, retreated; and as the elevation of the floor went on, an interval was left between the talus and the limit of the black ledge, and along this interval lay the "canal." The annexed figure will serve to illustrate the point, notwithstanding the assumptions made in it. Let *b b'* be the wall of the lower pit, four hundred feet high, and the course of the fault-plane; *a b*, the floor of the pit; *b' c*, the surface of the black ledge. Let now the falls from the wall above *e* make the talus *d e b* with a slope of 45°, causing thereby the wall (and limit of the black ledge) to retreat to *g*. If the floor be now lifted four hundred feet, to the position *a' b'*, the debris of the talus *d e b*



would make an elevation at top equal to $d'\ e'\ b$, besides filling up $e\ f\ b'$ ($e\ f\ b' = d'\ e'\ b' = \frac{1}{2}\ d\ e\ b$); the interval $b'\ f\ g$ would represent the canal, and $d'\ e'\ b'$, one hundred feet high, the ridge.

If the floor were raised fifty feet higher, the ridge would be lowered, say twenty-five feet, owing to material that would slip down into the canal; and consequently, the height of the ridge above the floor over the centre of the crater would then be twenty-five feet less than before, while twenty-five feet more than it was above the black ledge. If no talus had been formed at the foot of the wall, an uplift of the floor of five hundred feet would have made a precipice of one hundred feet fronting toward the black ledge, the falls from which would have produced a steep talus. These are two conditions in the different parts of the ridge mentioned in Mr. Lyman's paper.

Fault-planes about Halema'uma'u. — In Halema'uma'u, at the eruption of 1876, there was a circumferential fault-plane; this seems to be implied in the fact that the return of lava was mostly through vents toward the walls, little coming up at the centre, and the fact that even a year and a half afterward the action was greater outside of the cone than at its centre. At the discharge, the debris from the tumbling walls fell beyond the fault-plane and made an accumulation of blocks, like the talus of the lower pit of 1840; and this, as Mr. Dodge's description shows and the photographs illustrate, was the material that became the cone as the lifting went forward.

Conclusion. — By the above facts, it is proved that the conduit lavas of the volcano not only keep up the supply of heat, and carry on, by means of the vapors, projectile action and vesiculation, but also that they furnish power for lifting, in a quiet, unperceived way, the floors of craters with whatever is upon them, and thus raising the level of volcanic

activity; and that this goes forward as part of the *ordinary* operations of the crater. The action has long been recognized as a means of supplying heat and lavas, but not as a mechanical agent to the extent here indicated. The force at work in making the Gilbert laccoliths must be the same; and Mr. Gilbert, in his report on the Henry Mountains, gave the first intelligible idea of its power.

But there is nothing in the action that leads us to suppose that it can, under any probable conditions, make jets or fountains of lavas, or work in blow-hole style. Each jet over a lake, and each large jet in a lava-fountain, has its local projectile cause beneath the projected column of lava, and cannot be produced by any general upthrust movement in the great conduit. The imperceptibly slow uplift and fountain-making are incompatible effects. There seems to be, therefore, no foundation for the comparison of the lava-fountains to the projectile effect in an "artesian boring made to a stratum of molten rock which had only been awaiting an opportunity to overflow." [1]

The *source of the ascensive movement* has not been ascertained. It is most commonly referred to the pressure of the earth's crust on the lava-reservoir beneath, arising from subsidence in the earth's crust from secular refrigeration. Another explanation appeals to vapors from the deep source of the lavas. The possibility of some addition to the force through ascending vapors is referred to on page 168 of this volume.

c. EFFECTS OF HEAT.

From Change of Temperature. — Contractional effects from cooling — that is, fractures and changes of level — should be common in the crater; for each stream has passed from a tem-

[1] Mr. W. L. Green, Vestiges of the Molten Globe, pp. 168, 272. Mr. Green's examples are taken from action in the summit crater; and when speaking of that crater, this point will be again considered.

perature of 2000° F. or more to 70° or 80° F., and the upper surface of a stream rapidly so. Besides ordinary shallow fractures, the cause produces also an imperfectly columnar structure in the cooled lava-stream below the upper foot or two. The cracks in the floor of Kilauea often expose quite good basaltic columns even when the whole thickness of the layer is hardly a dozen feet.

There should be also larger effects in the Kilauea region arising from change of temperature between periods of great and little activity, or from periodical variations in the heat below, and changes of level in the lava of the conduit. But we have no special facts to report in illustration, although there are cracks innumerable in view that probably have this source.

The Dissolving Action of the Liquid Lavas. — (1) *The refusion of the crust* over the surface of a lava-lake by the liquid lavas is — as the history has shown — one of the common occurrences in Halema'uma'u and other lava-lakes. The intervals of cooling and refusion vary in length from a few seconds to an hour and longer. The crust of a lava-lake is often only the thin, easily fusible glassy scum; but thicker crusts also yield to the heat.

In the case of rapid transitions, the cooling may be due to the loss of heat by the expansion in the process of vesiculation; and if the vesiculation takes place intermittently for any reason (as from oscillating movement in the lava-column or other condition) it would occasion the alternations between the fused and crusted state. But for the crustings at longer intervals deeper movements may be concerned, and more study is needed before they are fully understood.

(2) *The disappearance of floating islands* is another effect of heat and chiefly of refusion; for in some cases the islands have after a while — a year or more — disappeared.

(3) *The destruction of debris-cones* in Halema'uma'u is dependent on undermining by the active lavas and vapors

beneath; and in one case the destruction was probably completed before a period of eruption.

The debris-cone, fifteen hundred to two thousand feet broad at base, which now occupies the centre of the Halema'uma'u basin, is already in process of dissolution, as stated on page 110. It made no increase in height during the summer of 1887, but, instead, rather lost ground through the changes going on; and the report of the spring of 1889 tells of a loss already of eighty feet in its height, — not eighty feet of its summit, but of the lower part that was within reach of or in contact with the liquid lavas.

The description on page 105 by Professor Van Slyke of the cone as seen by him in July, 1886, gives particulars as to the steam-holes in and beneath the cone, and of the blowing-cone work which began this work of destruction.

This destructive work brings the cone to its end either before or during a period of eruption; and a floating island may be the last phase before its disappearance.

Opening of New Lava-lakes. — With the intensifying of the fires of the crater there has often been, as the history shows, an opening of lakes over the interior of the crater, and especially along the borders of Kilauea, or the region of the black ledge. Such facts signify, as has been explained, that the broad underlying conduit of Kilauea, which is like a great reservoir of lavas beneath the pit, reaches at such a time up to the surface, not only in the Halema'uma'u basin through the great conduit, but also in minor lakes through secondary conduits. It is a query whether this has ever been brought about by new sources of vapor starting in the underlying reservoir as a consequence of subterranean conditions; whether hot vapors from such a source have not forced a way through to the surface in consequence of their own dissolving and fusing heat and that of the lavas, and thus have made a new lake, — as ascending air from the bottom of an ice-covered pond makes a hole through the covering of ice. But

such lakes, as remarked on a preceding page, are generally begun over fissures; and it may be that fissures under the general increased activity are all that are needed for the result.

Extending the Limits of the Conduit by Fusion. — Another suggestion comes from the fusing power of the Halema'uma'u lavas. If these lavas can slowly, even at their surface, fuse stony lavas, what is the extent of the fusing power at depths below where there is greater heat? An increase in the heat from a subterranean cause would necessarily widen the limits of the conduit. It is a question whether an extended subterranean bed of liquid lava, thick enough to remain permanently liquid in spite of cooling agencies about it, can occupy its place without fusing and incorporating with itself any solid lavas directly underneath it, if such there be. A great lava-conduit, therefore, has probably its varying phases, like the fires at the surface, and includes extremes in breadth or enlargement as well as in contraction. The widest part should not be at the summit unless the cooling agencies are *less* effective, or the heat-making causes more effective, there than elsewhere.

The Metamorphic Action of the Heat. — Metamorphic action also may be part of the quiet work of the volcano. The lava-column has its enclosing rocks, and at temperatures varying from that just below fusion to that of the outside rocks; and vapors must be active in the hot regions. The throat of the conduit may well be, therefore, a region of recrystallizations, of the making of geodes, or the lining of fissures with crystals, out of whatever material was at hand, and different kinds, somewhat according to the temperature. The effects of such metamorphism are exhibited, beyond question, in the various mineral crystallizations of the ejected masses of Vesuvius. They are found also at Kilauea, as mentioned beyond. The repeated coolings and heatings (passing often to fusings), which Kilauea lava-lakes so well

illustrate, suggest an explanation also for the feathery augite detected by Prof. E. S. Dana in the lavas of Kilauea as well as of Mount Loa, as described beyond.

D. HYDROSTATIC AND OTHER GRAVITATIONAL PRESSURE.

1. The hydrostatic pressure of the column of liquid basalt is 2·8 to 2·9 times that of water, supposing the lavas while in fusion to be mainly in the glassy condition. This pressure was early recognized by Lyell as one of the possible causes of rupture in volcanoes. The cause may have its effects in a quiet way over the bottom of Kilauea, since the lavas often stand in the lakes at a height of fifty to a hundred feet above the floor outside of the surrounding cone; but no facts yet observed can be positively referred to it.

2. Again, there may be *underminings* and therefore *subsidences* in the ordinary course of Kilauea changes, through discharges following small fractures. Such effects over the floor of the pit are not at present distinguishable from those of other modes of origin. But the sinking of the floor of Halema'uma'u in the spring of 1889, mentioned on page 123, is probably an example within this subordinate pit.

Having thus reviewed the ordinary operations of the crater — that is, those carried forward *between times of eruptions* — in the way of preparation for an eruption, the next inquiry is, What is needed to produce a great eruption of Kilauea? The power of the rising vapors and that of the ascensive conduit-lavas — the two chief sources of ordinary activity — appear to be too feeble for any such result. Can eruptions take place without any increase of their activity within the crater beyond what has been described? If so, how?

Before discussing this subject the history of the summit crater, Mokuaweoweo, should be first reviewed, as its facts afford important illustrations of the eruptive methods.

B. MOUNT LOA, AND ITS SUMMIT CRATER, MOKUAWEOWEO.

The map of the island of Hawaii, reduced from the Government map, making the frontispiece, should here be studied. It will enable the reader to appreciate the broad, almost plateau-like summit of the mountain, the relative position and heights of Kilauea and the Mount Loa crater, besides other points of interest in the history and discussion beyond.

The present form of the summit crater, Mokuaweoweo, is shown on the map (Plate X.) by J. M. Alexander, reduced from the results of his survey. The height of the highest point given on it — 13,675 feet — differs eighty-five feet from Wilkes's determination of the same point in 1841.

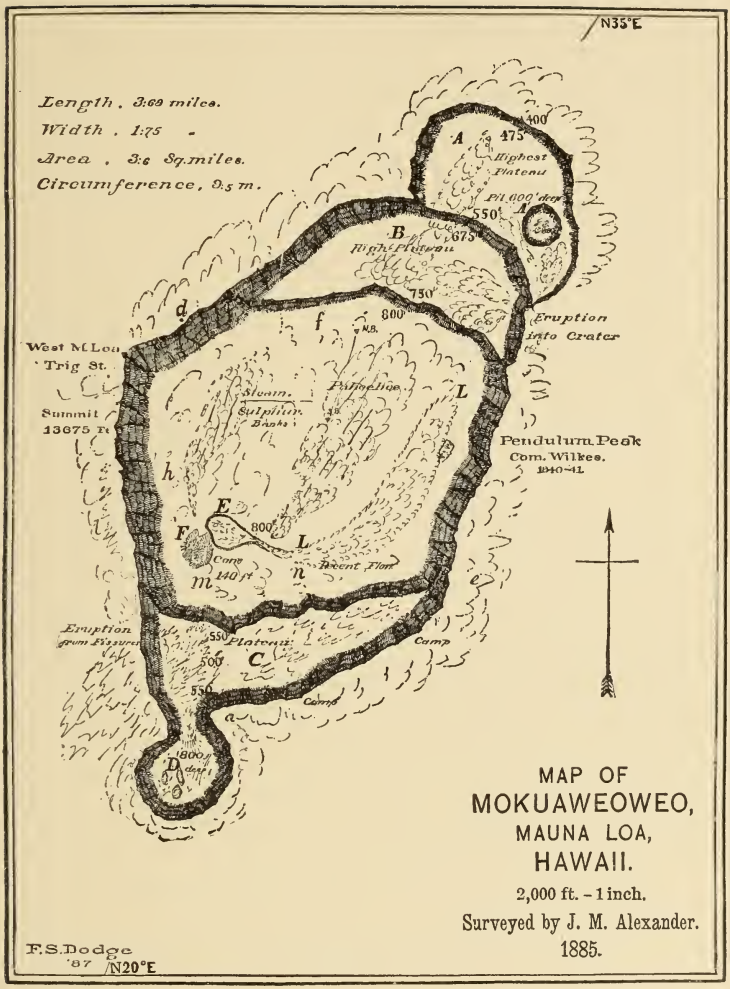
The *history* of the summit crater is mostly a history of the results of its eruptions, for few facts have been observed respecting the action *within* the crater. It has excited attention when an eruption has been in progress; but the chief outflows have begun below the summit, and the source of the outflow is usually the only place reached. Still there is much to be gathered from the reported facts. The records begin with the year 1832.

1. Eruptions of Mount Loa from 1832 to 1868.

1832, *June* 20. — On the 20th of June, 1832, according to Rev. Joseph Goodrich, lavas were discharged from several vents about the summit.[1] The fires continued to be visible for two or three weeks, and were seen from Lahaina, on the western coast of Maui, a hundred miles to the northwest.

[1] Goodrich, American Journal of Science, 1834, xxv. 201, letter of Nov. 17, 1832.

Plate X.


N35°E
Length, 3.69 miles.
Width, 1.75 "
Area, 3.6 Sq. miles.
Circumference, 9.5 m.
A
Highest Plateau
B
High Plateau
Eruption into Crater
West M. Loa
Trig St.
Summit
13675 ft.
Steam
Sulphur Banks
Pit 600' deep
Pendulum Peak
Com. Wilkes.
1840-41
E
F
Cone
140 ft
Recent Flow
Eruption from Fissures
Plateau
C
Camp
D
800' deep
MAP OF
MOKUAWEOWEO,
MAUNA LOA,
HAWAII.
2,000 ft. - 1 inch.
Surveyed by J. M. Alexander.
1885.
F.S.Dodge
'87
N20°E

Nothing is known of any large discharge of lava, and no mention is made of accompanying earthquakes.

The outbreak of Kilauea in 1832 occurred about the same time, but possibly a few months later.

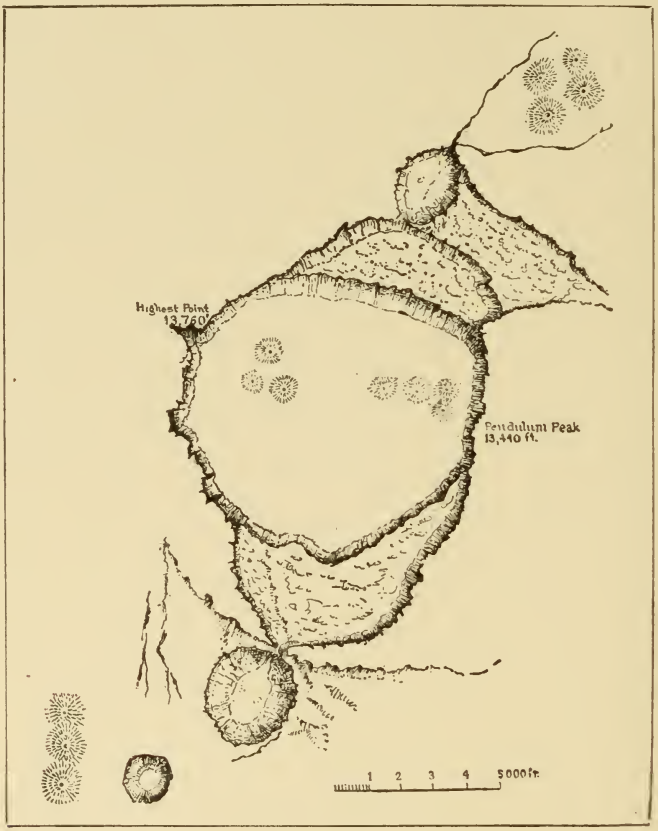
1834, *January* 29. — Mr. David Douglas, the naturalist, who was the first to ascend Mount Loa and determine barometrically its altitude, describes the crater, in his "Journal," [1] as having great chasms in the bottom that he could not fathom "with a good glass and the air clear of smoke," and says further that "the depth to the bottom on the east side was by an accurate measurement with a line and plummet 1,270 feet;" that the southern part of the crater, "where the outlet of the lava had evidently been, must have enjoyed a long period of repose." He mentions hearing light, hissing sounds from fissures in the summit, that might "perhaps be owing to some great internal fire escaping." He adds: "There is little to arrest the eye of the naturalist over the great portion of this huge dome, which is a gigantic mass of slag, scoriæ, and ashes."

1841, *January*. — Captain Wilkes was at the summit during the latter part of January, 1841.[2] Lieutenant Eld, by taking angles from the bottom of the crater, made the western wall 784 feet high, and the eastern 470 feet. The only sign of activity was the escape of steam and sulphur gases from many deep fissures over the bottom, especially on the west side. The fissures had generally a N.N.E.–S.S.W. direction. There was one cinder or scoria cone at the bottom,

[1] Companion of the Botanical Magazine, 1836, ii. 175, and in a letter to Captain Sabine, dated May 3, 1834 (Journal of the Geographical Society, 1834, iv. 333). See page 58, on the letter to Dr. Hooker and the evidence against it.

[2] Narrative of the Expedition, iv. 152, 156, 159. The descriptions of the crater are from descents made into it by Dr. G. P. Judd of Honolulu (p. 152) and Lieut. Henry Eld (p. 156). Wilkes's map has its longer diameter, through some mistake, north and south in direction; this is corrected in the copy on the following page.

according to Dr. G. P. Judd, toward the southwest side, having a height of about two hundred feet. Other steam-cracks were observed outside about the pit-crater of the south-southwest end; and one, which they "designated the great steam-crack, led from the top a long distance down the sides of the mountain toward the south;" and a great depth was indicated



THE SUMMIT CRATER.

by the reverberations from a block of lava which was dropped into it. Small driblets of lava were observed along some of these fissures, indicating feeble ejections. In Wilkes's map, as shown in the above outline copy, seven small cones are faintly represented on the bottom of the crater, although the descriptions speak of only one.

1843, Great Eruption commencing in January. — In January, 1843, began an outflow that continued for about six weeks. Clouds above on the 9th made the first announcement to the people of the islands. During the following night, according to Dr. L. Andrews,[1] a brilliant light appeared at the summit, looking, as Mr. Coan states, like "a small beacon-fire." [2] In a week the light disappeared. In the mean time the lavas had commenced their discharge. Mr. Coan ascended to the source, about eleven thousand feet up, and found two large craters near together, very deep and active. The stream of lava flowed toward Mount Kea, but gave off a westward branch, toward Hualalai, near its source. At the base of Mount Kea a branch went northward toward Waimea, and another eastward toward Hilo. Mr. Coan states that over the crusted surface of the stream were many steaming openings, twenty to fifty feet broad, down which he saw the lavas rushing along the tunnel-like way, "with awful speed, some fifty feet below us;" large stones thrown on the surface were carried "instantly out of sight before sinking into the stream." The action was much diminished in six weeks, but was "still somewhat vehement at one or two points." In March of 1843 Messrs. Paris and Coan found snow on the summit.

Mr. Andrews states that during the progress of the eruption Mr. Wilcox visited Kilauea and found no signs of sympathy.

1849, *May.* — A brief notice of brilliant fires at the summit crater in the month of May, 1849, is contained in a letter of Mr. Coan's, dated January, 1851. He says that the light was first noticed *after* the extraordinary activity in Kilauea. "I cannot say that they were coincident." For two or three

[1] Andrews, Missionary Herald, xxxix. 381, letter of Feb. 6, 1843.

[2] Coan, Ibid., xxxix. 463, letter of Feb. 20, 1843; xl. 44, letter of April 5; American Journal of Science, 1859, 2d series, xxvii. 411; Life in Hawaii, 1882, p. 270.

weeks a brilliant and lofty column of light was seen over the mountain. There is no reported evidence as to any surface outflow of lavas, and none of an earthquake.[1]

1851, *August* 8. — A short flow commenced at this date a few miles west of the summit.[2] From Hilo a column of clouds was seen by day, which was fiery by reflection at night. The eruption continued, so far as could be seen from Hilo, only three or four days. No earthquake was reported.

Mr. William T. Brigham in 1864 visited the flow, and states[3] that the outbreak of 1851 occurred about a thousand feet below the summit, "or two hundred feet below the bottom of the crater." He estimated the length of the stream at "ten miles and the average breadth less than a mile," and the volume "one hundred and sixty million cubic yards of lava." "The greater part is the pahoehoe, although some *aa* occurs." The course was westward, near that of an old stream toward Kealakekua.

1852, Great Eruption commencing February 17. — The eruption of 1852 began only six months after the brief action of 1851, as if its supplement. The place of outbreak, according to Mr. Coan,[4] was on the north side of the summit, near that of 1843. When first seen the light looked like "a planet just setting" over the top of the mountain. In a few minutes the whole summit was brilliant, and Hilo also; and a stream of lava commenced its flow down the mountain. Forty hours later the fires had apparently become extinct.

But after three days, on the 20th, the chief flow began at

[1] Coan, American Journal of Science, 1851, 2d series, xii. 82, letter of January, 1851.

[2] Ibid., 1852, xiii. 395, letter of Oct. 1, 1851; and D. D. Baldwin, Ibid., p. 299, from "Polynesian" of August 23, 1851.

[3] Volcanoes of the Hawaiian Islands, 1868, 4to, p. 389.

[4] Coan, American Journal of Science, 1852, xiv. 105, 219; Life in Hawaii, p. 279.

a point on the eastern side about ten thousand feet above the sea-level, near the terminus of a line of fissures leading down from the place of the first outbreak. *The escaping lavas rose at first in a lofty fountain,* and then flowed eastward for twenty miles. On the 27th Mr. Coan reached the place of the fountain, approaching it on the windward side within two hundred feet. He found the lavas playing, as he states, to a height of four to five and seven hundred feet, by angular measurement, in ever-varying forms of towers, pyramids, and spires, and with variations also in colors from white heat at base to red above, and then to grayish red and gray.

Great volumes of lava were ascending and descending, not intermittently but continuously; and the "surging, roaring, booming" sounds were almost deafening, but without earthquake from beginning to end. Ashes and capillary glass fell in the streets of Hilo. The stream stopped about ten miles from the village. The grand eruption was in blast only twenty days. All this time Kilauea was quiet.

In July Mr. Coan ascended again to the crater or place of discharge,[1] and found the fires extinct. He says a kind of "pumice" was abundant and widely scattered; "we found it ten miles from the crater, and it grew more and more abundant till we reached the cone, where it covered the whole region to a depth of five or ten feet."

An ascent to the active fires was made early in March by Mr. H. Kinney[2] and Mr. Fuller. Mr. Kinney, speaking of the sounds from the cataract of liquid lavas, says: "Its deep unearthly roar, which we began to hear early on the day before, waxed louder and louder as we drew nearer the action, until it resembled the roar of the ocean's billows when driven by the force of a hurricane against a rock-bound coast,

[1] Coan, American Journal of Science, 1853, xv. 63.

[2] H. Kinney, American Journal of Science, 1852, xiv. 257, from the "Pacific" of San Francisco of June 19, the letter dated Waiohinu, Hawaii, April 19, 1852.

or like the deafening roar of Niagara." This description attests to the fountain-like character of the discharge; for such sounds do not come from flowing lavas unattended by earthquake phenomena. Mr. Kinney made the height of the jets four to eight hundred feet. He reports also that the heat created terrific whirlwinds which stalked about like so many sentinels, bidding defiance to the daring visitor.

Mr. Fuller states[1] that from careful calculations, made "after deliberate discussion with Mr. Kinney," "some of which," he says, "have been confirmed by a somewhat accurate measurement by Mr. Lyman of Hilo," the diameter of the crater from which the fountain rose was about a thousand feet; height of the crater, a hundred to a hundred and fifty feet; height of the fountain, two to seven hundred feet, and rarely below three hundred feet; diameter of the fountain, one to three hundred feet, "and rarely perhaps reaching four hundred feet." The jet of fire sometimes shot up into a tapering gothic spire of seven hundred feet, then rose in a grand mass three hundred feet in diameter, but varied at top with points and jets like the ornaments of gothic architecture. He adds that to appreciate the most terrific element in the sublime composition you should stand at the foot of a Niagara, or on a tempest-lashed shore; for "the force necessary to raise two hundred thousand to five hundred thousand tons of lava at once into the air would not be silent in its operations." The lava-stream is stated to have a depth, in some places, of two or three hundred feet.

Mr. E. P. Baker states that on the route from Ainapo to the source of the outflow of 1852, the lavas of the 1852 stream, where they were first reached, were of the *aa* kind; but after a while there was a change to pahoehoe, and soon after this the source was reached. — a red cone in the midst of an extensive bed of pumice. Long ditches or trenches

[1] Fuller, American Journal of Science, 1852, xiv. 258, letter dated Waiohinu, March 28.

occur in the surface of the region, which were evidently the beds of lava-streams, their sides having been the banks. The flow appears to have had a single outlet. Water boiled at the source at 200° F.[1]

1855, Great Eruption commencing August 11. — During the evening of August 11 a glowing point of light was seen at a height of twelve thousand feet on the northeast slope of the mountain.[2] The light rapidly extended, and it soon became evident that a lava-stream was on its way down the mountain. No earthquake had announced the eruption.

Mr. Coan ascertained, through his excursions, that a line of fissures extended from near the summit for "five miles" down the northeast side to the place of outbreak, along which there were cones of volcanic scoria and sand, a hundred feet or so high, that had been thrown up at the points of greatest activity. Descending the mountain the cones became lower and less frequent, and were the ragged jaws of orifices through which the stream of lava was visible.

The place of outflow was a crater formed over a fissure two to thirty yards wide. The lava flowed in a continuous stream down slopes of all angles from less than one degree to verticality. The course was eastward like that of 1852, and it finally stopped within five miles of Hilo.

Mr. Coan describes the tunnels in the lava-stream, and speaks of the lavas seen through openings as moving with great velocity, — "estimated to be forty miles an hour." Some of the steaming openings were thirty to two hundred feet long, and the flowing lavas were fifty to a hundred feet below. But the progress of the front of the stream, where were obstructions of trees, jungles, depressions, etc., was

[1] Baker, American Journal of Science, 1889, xxxvii. 53.

[2] Coan, American Journal of Science, 1856, 2d series, xxi. 139, 144, letters of Sept. 27 and Oct. 15, 1855; Ibid., p. 237, letter of Nov. 15, 1855; Ibid., xxii. 240, letter of March 7, 1856; Ibid., 1857, xxiii. 435, letter of Oct. 22, 1856; Life in Hawaii, p. 289.

"slow — say one mile a week." He observes that owing to the cooling, and the partial damming thereby along the front, the hardened upper stratum was raised by the descending stream into numerous tumuli of various forms and sizes as if by pressure from above, which became cones or domes, and let out lavas to flow over the surface and add to the thickness; that "upgushings" also occurred through fissures; and that thus layer was added to layer, increasing the thickness from a few feet to fifty or a hundred, and also retarding the progress of the stream. One dome on the stream was a hundred feet high and three hundred feet in diameter; and through the fissured top and sides the liquid lavas were visible, and easily reached by the pole he had for measuring the thickness of the cap, — two to five feet. These effects were especially great where the slope was very small. Pressure of the lavas above, and gases or vapors from the burning of trees and other vegetable matter buried by the lavas, are made the causes of the uneven surface of the lava-stream.

The stream, in addition, became widened by the lateral out-gushings, divided into a number of channels, and shifted to the right or left. After flowing freely for a while, the stream often suddenly cooled and hardened along the front and remained for several days inactive; "at length, immense areas of the solidified lava, four, five, or six miles above the extremity, are again in motion, cones are uncapped, domes crack, hills and ridges of scoria move, and great slabs of lava are raised vertically or tilted in every direction."

On the 22d of October, 1856, the stream was within five miles of the sea-coast north of Hilo, still pushing out and spreading itself. Mr. Coan says that the lavas were even then flowing in the tunnel-ways from the place of outbreak to the lower extremity, although no fires were seen, — evidently an opinion rather than a direct observation. He argues for the absence of fissures beneath the stream for the supply of lava, from the absence of steaming vents and cones.

After fifteen months, in November, the fires ceased action. The stream includes many square miles of *aa* and immense fields of pahoehoe.

1859, Great Eruption commencing January 23. — Prof. R. C. Haskell (of a party to the place of eruption including also Professor Alexander and President Beckwith) reports[1] that on the 23d "smoke" was seen over the summit from Waimea by Mr. Lyons of that place. In the evening lavas were ejected, and the light was bright enough at Hilo, thirty-five miles east, to read fine print. "No earthquake was felt in any part of the island." But dead fish, apparently par-boiled, were found in the sea to the northwestward, both east of Molokai and between Molokai and Oahu.

The stream flowed northwestward by the foot of Hualalai, "turning just enough northward to fetch by the northeastern flank of this mountain," and reached the sea on the 31st of January at Wainanalii, a dozen miles south of Kawaihae, a distance in all of thirty-three miles in eight days. The chief source was probably about 10,500 feet above the sea-level. Above this point, for four miles, a fissure, two inches to two feet wide, descends the mountain, from which some lavas escaped. Several cinder-cones stand along the line of fissures, and two of them near its extremity. Half a mile farther down the outflow began.

The lavas, "white hot" as they escaped, were thrown at once, as at the 1852 eruption, into a fountain, the height of which, according to Mr. Vaudrey, who happened to be on the mountain at the outbreak, was three or four hundred feet.

On the 9th of February the issuing lavas were "at a white

[1] Haskell, American Journal of Science, 1859, xxviii. 66, 284 (the latter from letter of June 22); 1860, xxix. 301, letter of November 5. There are shorter reports by the Editor of the "Commercial Advertiser" of Oahu, and Rev. L. Lyons, Ibid., 1859, xxvii. 412; and Coan, Ibid., xxvii. 415, letter of Feb. 2, 1859, and xxix. 302, letter of Nov. 25, 1859. W. L. Green, Vestiges of the Molten Globe, 1887, pp. 163, 270, 280.

heat and apparently as liquid as water." The report says that the stream below dashed along in cataracts and rapids at such a rate that "the eye could scarcely follow it." For eight to ten miles there was a succession of cascades and rapids, some of them a consequence of obstructions met on the way and others due to the obstructions which the stream made. The lava flowed more gracefully than water and with great velocity, following the surface beneath, rising as it rose, and turning abruptly, with the outside of the stream higher than the inside, the mobility being perfect.

Both pahoehoe and *aa* were formed. The *aa* portions are described by Professor Haskell as produced by deep lava-streams, — streams flowing sluggishly where the slopes are small, which become dammed up in front by the cooling, by the breaking up of the cooled barrier and crust, and by the rolling over and over of the stream. Often at the end of the *aa* stream no liquid lava could be seen, and the only motion was the rolling of the jagged rocks of all sizes down the front of the embankment. Sometimes it broke through the embankment, and flowed on, "carrying jagged rocks of all sizes on its back, which looked like hills walking;" then it became clogged again, with finally a repetition of the process of breaking up and piling.

The stream, after reaching the seashore, continued flowing into the sea till after the 25th of November. The surface of the stream was of black hardened lavas; but at the sea-border the liquid lavas ran out at a red heat, having flowed under cover. Professor Haskell states, for at least twenty-five miles, if not from the source.

According to Mr. W. L. Green, the column of vapor that rose from the orifice or crater, alongside of which his tent was pitched, was five hundred feet wide and ten thousand feet high. He says: "From the whole interior of this crater rose the great illuminated column of smoke perpendicularly, and then at a great height in the atmosphere it spread out on

all sides." It continued for many weeks, but ceased before the flow was ended. The lava appeared to have broken out at the intersection of two fissures. Over the surface in the vicinity there was a thick deposit of "pumice" or "glass-foam." The top of the mountain at the time was covered with snow, — a source of percolating water. While Mr. Green was near the stream, on the plain between Loa, Kea, and Hualalai, "loud explosions were heard all night long, like the reports of heavy cannon."

Mr. Green also states, from his observations, that at the seashore the lava ran over a low shelf about ten feet high and five or six hundred feet wide, and fell into the sea where the water was twenty or thirty feet deep. "It came from under the crust in great red-hot flattened spheroidal masses, having something the appearance of moderately thick porridge as it is poured from a saucepan, — the spheroidal masses perhaps ten to fifteen feet wide and four to six feet deep. . . . There was no steam, vapor, or gas whatever to be seen coming from the lava until it went under water. Indeed, the first contact of the red-hot spheroids did not seem to produce a particle of steam, and it was only when each had gone under water and become partially cooled off that a puff of steam rose above the water, . . . an effect due to the spheroidal state of the water against the red-hot surface."

No sympathy was exhibited by Kilauea. Mr. Coan says: "We have occasional earthquakes, — two in February, one in July, and two in November of the current year (1859)."

In June, according to Professor Haskell, there was no action in the summit crater.

1864, *August* 5. — Mr. W. T. Brigham found the summit crater, at this date,[1] without any signs of action excepting some "steam issuing from the northern bank." There were two cones at bottom, about two hundred feet high, near the

[1] Memoir, p. 384.

east side. He also observes that in various places over the great plain about the crater there "were large irregular masses of a solid reddish clinkstone, much used for stone axes," and speaks of the "hard compact graystone of the summit and walls."

1865, *December* 30. — Light, says Mr. Coan, was seen "at the very summit," on the night of the 30th of December.[1] It continued, with variations in intensity, sometimes very brilliant, at others faint or gone, for four months, or until the last of April, or perhaps into May. Mr. Richardson, proprietor of the Volcano House, reported the occasional escape of steam, but no outflow of lava is known to have occurred. "The falls of snow on the mountains this winter have been frequent and heavy, extending almost to their bases." No earthquakes were reported. "As it was winter, no one ascended the mountain." In May a great increase of activity began in Kilauea.

1868, Great Eruption commencing in Earthquakes. March 27. — On March 27, Friday, many slight earthquakes were felt in Kau, southern Hawaii, and in Kona, the southwestern district. On the 28th they were more energetic and frequent, and extended east to Hilo, and northward through Kona. Mr. T. D. Paris, of Kealakekua, South Kona, reports[2] that on the morning of Friday fire and great columns of "smoke" were seen at the summit; and on Saturday the 28th the fires were visible from Hilo, according to Mr. Coan.[3] Mr. F. S. Lyman reports, from Kau, that the first outbreak was a little to the southwest of the summit; that others followed, and soon the lavas were seen in four streams running down the mountain in a southerly and easterly direction.

[1] Coan, American Journal of Science, 1866, 2d series, xli. 424, letter of Feb. 27, 1866; and xliii. 264, 1867, letter of August 31, 1866.

[2] Paris, American Journal of Science, 1868, 2d series, xlvi. 107.

[3] Coan, Ibid., p. 106; F. S. Lyman, Ibid., p. 109; H. M. Whitney, Ibid., p. 112

By Sunday (the 30th) the line of smoke had advanced about fifteen miles on a line toward Captain Brown's house in Kahuku. (See southern part of map of Hawaii.) But the light of the summit had disappeared; it was not seen at Hilo after the 28th.

During this time, however, the earthquakes became still more violent and destructive, and almost continuous. On Thursday, April 2, at four P. M., occurred "the terrible shock," destroying houses and life, making fissures of great length and depth, dislodging rocks, and half a mile in breadth of marshy earth from the mountain side of Kapapala, to the destruction of a native village, besides raising earthquake waves on the southern coast, that swept away the villages of Punaluu, Ninole, Kawaa, and Honuapo. The position of the land-slide is shown on the map of Hawaii (Plate I.). It was also violent to the eastward in Hilo, the only stone building being thrown down, and furniture in other houses; but so light on Oahu, two hundred miles to the westward, that most of the inhabitants of Honolulu were unaware of it, those in stone houses being almost the only persons that felt it.

On the 7th of April the lava escaped from a wide fissure in the district of Kahuku, about fifty-six hundred feet above the sea-level. Along the fissure, in the course of a mile, the escaping lavas were thrown into four fountains, which were playing on the 10th, when the place was visited by Mr. H. M. Whitney, of Honolulu. According to this writer's description, the fountains rose to a height of five to six hundred feet, along the line of the fissure for a mile. The lavas were "blood-red, yet as fluid as water." Sometimes two of the fountains joined, and then all four were united. At one time they subsided for a few minutes, and then burst out again and went to a height of a thousand feet. Large stones and rocks were thrown up, some weighing a hundred tons; and so many that they seemed to fill the air. The lava of the fountains is stated to have had a rotation "to the south."

Below the fountains the lava flowed in a rapid stream to the sea, making a descent of two thousand feet, and reaching the shore in two hours. The rate of flow is stated to have been ten to twenty-five miles an hour.[1] A cinder or tufa cone was made at the place of discharge into the sea, which was first an island, and afterward became joined to the land by the flowing lava. The eruption ceased in the night between the 11th and 12th, after only five days' activity. The lava is mostly pahoehoe, with some areas of *aa*, and extremely chrysolitic. At the crack above the main outburst, the lava which escaped was light brownish scoria, which was drifted by the winds, along with much capillary glass. The season was one of unusual rains over the mountain.

Prof. C. H. Hitchcock examined the region of eruption in June of 1885, both above and below the extremity of the pali (precipice) represented on the map (Plate I.) as running along by the west side of the lava-stream. He states the following facts to the author in a letter of May 30, 1888: The fissure whence the lavas of 1868 flowed, is in exact continuation of the pali, up the mountain. I traced it fully three miles. For much of the way it makes a narrow cañon forty to fifty feet wide at the maximum, and so deep that it is dangerous to explore it. In the lower part heat was still evident. The fissure is most prominent where the lava is in greatest amount. Its borders have the smoothed appearance that would result from an outflow of lava over its edge. The very uppermost point reached we estimated, from our aneroid, to be thirty-one hundred feet above Mr. Jones's ranch near the north end of the pali. There is no cone at that point, as there is at the sources of the 1855 and 1881 flows which I also visited. Every fact harmonizes with the

[1] Pacific Commercial Advertiser of May 9, 1868. See also W. L. Green's Vestiges of the Molten Globe, pp. 294–303. Mr. Green does not intimate that Mr. Whitney's description is exaggerated. According to Rev. E. P. Baker, the highest fountain, on the estimate of an observer, Mr. Swain, was not over two hundred feet.

view of a rent three miles long, allowing the accumulated lava to discharge in one or two days' time, instead of oozing out of a single small orifice for months. The connection of the fissure with the pali shows clearly the existence of a fissure along its whole length, which has been the seat of eruptions in ages past. This Kahuku flow was analogous to that of Kilauea in 1840.

2. Eruptions of Mount Loa from 1868 to 1890.

1870, *January* 1. — During the first two weeks of January much "steam and smoke" arose from the summit crater.[1] In the course of the preceding month Judge Hitchcock, of Hilo, with others, visited the crater, and found much escaping steam but no visible fires. Slight shocks of earthquakes often occurred, sometimes one, two, or three a day.

1870. — Mr. Severance (as I learned from Rev. E. P. Baker, of Hilo) was at the summit crater in 1870, and found no action there.

1872, *August* 10. — On the night of the 10th of August, says Mr. Coan,[2] "a lofty pillar of light," two thousand feet high, — which means lighted vapors of this height, — stood over the summit crater, with varying brilliancy, indicating active fires within. The crater was "in full blast on the 27th," and continued so into September. On the 23d of August a tidal wave was felt on the coast at Hilo, the waters during a calm rising four feet, and in a second wave, six minutes later, three feet, and diminishing for about fourteen oscillations. It may have been part of the Mount Loa disturbance; but Kilauea also was unusually active over its interior. No earthquake is reported.

[1] Coan, American Journal of Science, 1870, xlix. 393, letter of Jan. 24, 1870.

[2] Ibid., 1872, 3d series, iv. 406, letter of August 27, 1872, and 1873, v. 476, letter of Feb. 14, 1873.

The "Pacific Commercial Advertiser," of September 21,[1] reports an ascent to the summit made just before this date. Near the southwest corner of the crater there was *a fountain of lava about seventy-five feet in diameter, playing, it is stated, to a height of five hundred feet.* The basin from which it rose covered about a third of the bottom, and was at the top of a low cone made by the falling lavas. Mr. J. M. Lydgate has informed me that he was at the crater in the latter part of August, and that the fountain was then in play.

1873, *January 6 and 7.* — On the 6th of January the action at the summit, as seen from Hilo, was "marvellously brilliant," the lighted vapors visible at night rising thousands of feet above the summit.[2] There was evidence, apparently, of active ebullition or a playing fountain; and this conclusion is favored by the fact that the herdsmen of Reed and Richardson's ranch, at Ainapo, on the eastern slope (forty-two hundred feet above the sea), stated that the mountain was "constantly quivering, like a boiling pot." The action suddenly ceased, without any known outflow; the time of ending the display is not mentioned. Kilauea had been very active for months. No earthquake is spoken of, and no sympathy with Kilauea implied.

1873, 1874. *Brilliant Summit Displays from April 20, 1873, to the Autumn of* 1874. — The summit display of January was followed, on April 20, three months later, by a return to activity, or to a degree of activity that was visible from Hilo. Mr. Coan observes that the lofty columns of light above the summit at night and of clouds by day were proof of violent ebullition within the crater.

[1] Coan, American Journal of Science, 1872, iv. 331, and 407, 408.

[2] Ibid., 1873, v. 476, letter of Feb. 14, 1873; 1874, vii. 516; 1877, xiv. 68. In the first of these notices the date given is January 27; in the others, January 6 and 7.

On the 6th of January, 1874, Mr. Coan writes[1] that for nine months the action within the great crater has not remitted. "The great marvel is its duration," without any outside results. There appears to have been a turn of special brilliancy in January. On the following October (the 6th) he says[2] the action has continued "for eighteen months, and the most of the time it has been violent. But of late it has become more quiet, and there is a prospect that it will soon cease." He adds: "We have had few earthquakes during the year, and these have been feeble. . . . Kilauea all this time was unusually active;" but no sympathy with Mount Loa was observed.

It is of great importance to the history that we have trustworthy reports with regard to the condition of the interior of the summit crater on three of the days during this era of prolonged activity. And as the first of the three—the 6th of June, 1873 — was a day of feeble summit light as seen from below, it affords data for an estimate of its condition during times of greater brilliancy. The explorer, Miss Bird,[3] was at the summit on the 6th of June, and describes well the condition of the crater. For the most part its floor was an area of solid black lava; but at one end (the southwest ?) there was "a fountain of yellow fire," one hundred and fifty feet broad, which played in several united but independent jets to a height of one hundred and fifty to three hundred feet. The party for the two days preceding had been under the impression that the fires had faded out; and yet this fire-fountain was all the time in action. When within two miles of the crater, monitions of the activity were apparent in a distant vibrating roar; and on reaching the crater edge, the roar was like that of an ocean, rising and falling

[1] Coan, American Journal of Science, 1874, vii. 516, letter of Jan. 6, 1874.

[2] Ibid., 1874, viii. 467, letter of Oct. 6, 1874; and 1877, xiv. 68, letter of March 17, 1877.

[3] Six Months in the Sandwich Islands, by Isabella L. Bird, London, 1876, pp. 266–273.

"like the thunder-music of windward Hawaii," — a comparison used also by Mr. Kinney in describing the eruption of 1852. At night the lake was for the most part at white heat, and its surface was agitated with waves of white-hot lava about the fountain at the centre. Through the rest of the vast crater the projecting ledges were thrown into bold relief by the reflected light, and by numerous dashes and lines of fire from apertures and crevices. Occasional detonations were heard, but no shakings except the tremors from the throw and fall of the lavas. At one time the jets, after long playing at a height of three hundred feet, suddenly became quite low, and for a few seconds there were "cones of fire wallowing in a sea of light," — a description that not only reads well, but I feel sure is to the life, like the most of Miss Bird's word-pictures; then, "with a roar like the sound of gathering waters, nearly the whole surface of the lake was lifted up, by the action of some powerful internal force, and its whole radiant mass rose three times in one glorious upward burst, to a height, as estimated by the surrounding cliffs, of six hundred feet. . . . After this the fountain played as before." "In one place heavy white vapor blew off powerful jets from the edge of the lake, and elsewhere there were frequent jets and ebullitions of the same; but there was not a trace of vapor over the burning lake itself."

In "The Vestiges of the Molten Globe" (p. 166), Mr. W. L. Green, with whom Miss Bird made her ascent, gives confirmatory facts. He makes the height of the fountain generally three to four hundred feet, as estimated from the known depth of the crater; and occasionally some spires shot up, he observes, to a greater altitude. He adds: "Among the varied forms of the fountain there were the low rounded dome; a spire at centre, with a fountain either side in the form of a wheat-sheaf; and one great wheat-sheaf." Besides a dull roar, there was "the metallic clink" from the fall of masses of lava of the fountain which were

cooled in the air; these cooled fragments formed a light falling veil over the dazzling fountain, and descending into the lake outside of the jets, made a scum over its surface. Only a light vapor was seen over the playing fountain.

Early in August, 1873, Dr. O. B. Adams ascended Mount Loa, at a time when the light at the summit was unusually brilliant. He found the fountain playing, he says, to a height of two to five hundred feet, and "assuming all the forms of a grand fountain of water." [1]

In October, 1873, Messrs. E. G. and H. R. Hitchcock spent one night at the summit near the site of Wilkes's camp, on the east side of the central crater or pit. They state that a fountain of lava was playing in the southwestern end of the crater, to a height of six hundred feet, this height being obtained by lying upon the brink and looking across the pit to the top of the opposite wall; "the column of fire ascended at least one half higher than the distance from the floor to the top of the walls, and taking this distance at four hundred feet, the height of the fountain was decided to be approximately six hundred feet." The descending lava of the fountain, falling into the basin, flowed off northward nearly the whole length of the western side of the pit.[2]

1875, *January.* — Mr. W. L. Green mentions the occurrence of summit action at this time for a month, in his tabular statement of eruptions, and says nothing of one in August of this year, to which date Mr. Coan refers the 1875 eruption. The report of the "Challenger," mentioned beyond, sustains Mr. Coan's statement, but does not positively set aside that of Mr. Green.

[1] Hawaiian Gazette, Sept. 3, 1873.

[2] Letter of W. C. Merritt, in American Journal of Science, 1889, xxxvii. 51.

1875, *August.* — Mr. Coan says:[1] "I think it was on the 11th of August that the summit crater was again in brilliant action. The action continued, as appeared in the view from Hilo, for one week, and without any observed evidence of an outflow."

In the first half of August, the day not stated, a party from the "Challenger" Expedition visited Kilauea. As reported in the first volume of the "Scientific Results of the Expedition" (p. 766), "a globular cloud" was seen over the summit of Mount Loa, which was "perpetually re-formed by condensation," and had "a brilliant orange glow at night, looking as if a fire were raging in the distance."[2]

1876, *February* 13. — Another grand display from the summit crater, but of short duration. No outflow is reported.[3]

1877. Probable Submarine Eruption, February 14. — The display of light on the 14th, says Mr. Coan,[4] was "most glorious." The columns of illuminated steam rose "with fearful speed to a height of fourteen to seventeen thousand feet, and then spread out into a vast fiery cloud, looking at night as if the heavens were on fire." The brilliancy continued only ten days.

No outflow is positively known to have occurred, but it is probable that a submarine discharge took place off western Hawaii. The steamer brought passengers from Honolulu to visit the mountain, but returned as the fire had disappeared. But before the vessel was fairly out of sight of land, "a remarkable bubbling was seen in the sea about three miles south of Kealakekua, a mile from the shore," and steam and scoria were thrown up. Mr. H. M. Whitney states that

[1] Coan, American Journal of Science, 1877, xiv. 68, letter of March 17, 1877.

[2] See also Moseley's Notes by a Naturalist of the "Challenger," London, 1879, p. 500.

[3] Coan, American Journal of Science, 1877, xiv. 68, letter of March 17, 1877.

[4] Ibid.

"blocks of lava two feet square came up from below, striking and jarring the boats;" and "nearly all the pieces on reaching the surface were red-hot; . . . as soon as they became cold they sank." This eruption took place on the 24th of February, the day the light disappeared from the summit.[1]

On the land new fissures were opened in the mountain which had a westward course toward the place of submarine disturbance. An earthquake is reported as having been felt in the fissured region, but not at Kealakekua. A heavy tidal or earthquake wave occurred about this time along the coast of Kona.[2]

1880, *May* 1. — Early in the morning of May 1 a light was seen at or near the summit, which soon after became so intense as to illuminate Hilo at night. It indicated violent activity, and led to an expectation of a great eruption. But clouds obscured the mountain for a few days, and when they disappeared, the light was gone.[3] On the 3d and 4th of May flocks of Pele's hair and light particles of volcanic dust, drifted by the wind, fell over Hilo. According to reports from Puna and Kau, the action had not ceased by May 6. Mr. Brigham states[4] that his guide was at the summit at the time, and saw boiling lava in the south crater; and that the tops of the jets were visible to the native while he was lying down some distance from the brink, — which would make the height of the jets, Mr. Brigham says, one thousand feet. As the depth of the crater was not over eight hundred feet, his estimate is probably too high. Mr. Goodale, one of the party who ascended at that time, reported, as

[1] Hawaiian Gazette, Feb. 28, 1877.

[2] On the 10th of May, 1877, a destructive earthquake wave was felt at the Hawaiian Islands, which rose at Hilo to a height of thirty-six feet. But it was of South American origin, where there were heavy earth-shocks, and not of Hawaiian.

[3] Coan, American Journal of Science, xx. 7, letter of May 3–6, 1880.

[4] Brigham, American Journal of Science, 1888, xxxvi. 33.

mentioned in a letter from Mr. E. P. Baker, that the lavas were thrown sixty or eighty feet above the brink of the crater on which the party were standing; and this confirms the report of the native guide.

1880. *July* 28. — On the 28th of July Mr. W. T. Brigham found the crater without action.[1] The walls were much fissured about the southern pit; fresh-looking lavas covered the bottom; and a small area was seen on the west border of the pit, which was probably of recent ejection. Moreover, about the region around the crater there was much of the spongy scoria, some masses a foot in diameter.

1880, 1881. Great Eruption from Nov. 5, 1880, to Aug. 10, 1881, Nine Months. — No "violent demonstrations or earthquake" announced the eruption. The first light was visible in the evening of Friday from Waimea, and a few hours later in the night from Hilo, and after midnight "the lavas could be distinctly seen leaping like a fountain into the air." The next day a line of light extended down the slopes toward Mount Kea, from a point about eleven thousand one hundred feet above the sea.[2] Near the same time another stream flowed from the source southeastward into Kau, and soon after the lavas commenced a third stream toward Hilo, between those of 1852 and 1855. The Kea stream stopped on the intermont plateau east of Kalaieha, having a length of ten to twelve miles; and the Kau stream reached nearly the same length. The Hilo, as the map shows, came near giving Hilo a burial. As observed by Judge Hitchcock[3] on the 10th or 11th, from the Kalaieha Hills at the south foot of Mount Kea, the stream, for miles northward to the plain, was

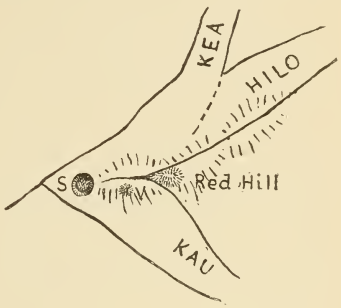
[1] Brigham, American Journal of Science, 1868, xxxvi. 33.

[2] Coan, Hitchcock, Ibid., 1881, xxi. 79, letter of Nov. 9–12, 1880; xxii. 227, 228, letter of June 28 and July 21, 1881, and xxii. 322, letter of August 24, 1881; Life in Hawaii, p. 325.

[3] Ibid., 1881, xxi. 79, and xxii. 226.

a continuous belt of fire in steady flow, and also beyond this for several miles toward Hilo. The regular flow was interrupted half-way from the plain to the source by the lavas rising into a huge dome, from which they flowed over like an immense fountain; but there was no fountain at the source.

Mr. E. S. Baker states,[1] after an examination of the region a second or third time, in July, 1888, that the Kea and Kau streams originated together from the same source, at the extremity of a long fissure where there is now a large pit crater, called Puka Uahi, as shown at S, in the annexed figure; and that the divergence of the Kau stream from the Kea and also from the Hilo stream was owing to the fact that the fissure followed the course of a "divide," so that a small obstacle was sufficient to turn the flow to one side or the other. The outflow took place on this divide; the Kau stream went off first from the fissure, or at least started off from it higher up, the Kea stream next, and the Hilo from a still lower point. The fissure ran by the north side of Red Hill, a cone with a deep crater which was still giving out vapors, and this hill was apparently the occasion of the turn southward of the Kau stream, it standing at the point of their divergence. This Kau stream is in general *aa*, but near the source, in a most quiet, unobtrusive way, the *aa* changes into pahoehoe. Near the head of the Kau stream there is a cinder-cone, named "Little Vesuvius" (at V on the map). This cone and the pit-crater were also steaming, although seven years had elapsed since the end of the eruption.



[1] Baker, letter to the author, and also American Journal of Science, 1889, xxxvii. 53.

The thickness of the stream in its lower part, as determined by the depth of the holes left where trees had been burned off, was found by Mr. Baker to be in two such places twelve and eighteen feet.

In four months the stream was within seven miles of Hilo, or about twenty-six miles long; in seven and two thirds months, June 28, within five miles; in eight and one half months, July 18, about *two* miles; and August 10, nine months after the outflow began, it stopped within *three fourths of a mile* of Hilo. On June 30, the movement just beyond the Hilo tufa-hills (the Halai Hills) was, as stated by Mr. D. H. Hitchcock, about seventy-five feet an hour.

On its way, says Mr. Ernest E. Lyman, "the lava-stream came in contact with a stream of water, flowed into, blocked, and turned it out of its course. The steam forming under it caused frequent explosions. I saw it pass over a water-fall. At first the water cooled the lava sufficiently to make it brittle, and it fell over in chunks till it had formed a pile as high as the fall; and then it flowed over, forming a flume of lava. It was a wonderful sight to see the water and the liquid lava flowing side by side."[1] Plate XI. represents another cascade in the same stream, two and a half miles above Hilo, and about half a mile below that described by Mr. Lyman.

In a communication to the "Commercial Advertiser" for November 20,[2] the formation of the *aa* or clinker fields is described as follows by Judge Hitchcock: "The whole broad front of the then sluggish stream was a mass of solidified lava twelve to thirty feet in height, moving slowly along by breaking and bearing onward the crusted covering; along the whole line of its advance it was one crash

[1] E. E. Lyman, communicated by President Merritt, in July, 1889.

[2] Hitchcock, American Journal of Science, 1881, xxii. 228, from the "Commercial Advertiser" of Honolulu.

Lava-cascade, Flow of 1881.

of rolling, sliding, tumbling, red-hot rock, no liquid rock being in sight; there were no explosions, but a tremendous roaring, like ten thousand blast-furnaces all at work at once. The rough blocks lie piled together in the wildest confusion, many as large as ordinary houses. They [clinker-fields] form only when the movement is slow."

While at Hilo in August, 1887, the author, under the guidance of Rev. E. S. Baker, of Hilo, visited the cooled lava-stream of 1880–1881, and its tunnel. The ropy twisted lines and tapestry folds cover much of the surface; and some are on a most delicate scale, the tapestry hangings (like that of page 117) only an inch wide, and varying from this diminutive size on one extreme to a breadth of six or eight feet. Three or four miles from Hilo the lava-stream, which had consisted of pahoehoe, became rather abruptly an *aa* stream. At the junction the pahoehoe was very much broken, as if by an intermittent flow in the stream.

The cavern, or rather tunnel, of the stream had very smooth sides, and in part a literally glazed surface, indicating the flow of the lava; and there were long parallel lines of mouldings, due to the same cause. One of the lines of mouldings had the form and position, along the side of the tunnel, of a solid, handsomely modelled bench, showing that the mouldings were due to projecting points and larger protuberances of the solid lava outside. The tunnel had a varying height of four to eight feet, but in some portions diminished to two feet, and in others rose to ten feet. The general width was about thirty feet; but there were large lateral expansions. The layer of rock above was two to six feet thick.

In some undisturbed parts of the tunnel there were thickets of long, slender, grayish-black stalactites, like pipe-stems in size, scarcely tapering at all except at the extremity where there is usually a short irregular twist (Plate XV.). Where most crowded they were twenty to thirty inches or

more long, and one every six or eight inches. Over the floor beneath each there was an irregular column of stalagmite of similar nature, consisting of a heap of bent, coalescing stems, of the same diameter, varying from a few inches to fifteen or eighteen in height. The stalactites were solid for the most of their length; but still many parts were hollow cylinders. A pocket lens was sufficient to show, after emerging again to daylight, that the texture of the stalactite was stony, like the lava, and contained similarly minute crystals of feldspar, which were lath-shaped on a surface of fracture; and that the cavities were lined with glassy crystals and magnetite.

I am informed by Mr. Baker, in a letter dated Hilo, July 3, 1889, that at one place in the tunnel, where the stalactites were only two or three inches long, their bent extremities were all turned one way, and that was toward a blow-hole entrance to the tunnel, — favoring the view, as he says, that a draught from the interior outward had determined the bending.

1882. — In this year (the month not stated) Capt. C. E. Dutton made his visit to the summit.[1] He found "no volcanic action whatever, . . . not even a wisp of steam issuing from any point." No mention is made of any cinder-cone at the bottom.

1883, *February*. — Prof. C. H. Hitchcock was at the summit on the 15th, and found no activity. "A snow-squall struck us, and *the entire floor of the crater was white with snow*."[2]

1885, *April*. — In April, 1885, Rev. E. P. Baker visited the crater and descended to its bottom. It was all quiet.

[1] Report, p. 139.

[2] Letter to the author of May 30, 1888.

1885, *October.* — In October, 1885, Rev. J. M. Alexander made a survey of the summit crater for the Government Survey.[1] The bottom of the crater was mainly flat, and covered with fresh lavas; it had two cones in it, as represented on the map, the southwestern a hundred and forty feet high and smoking; steam was rising from "hundreds of cracks," but no fires were visible. In the depressed area or terrace to the north of the central or main pit a circular pit-crater was found, as shown on the map, which was six hundred feet deep and a thousand feet wide, and had a cone at centre that was still smoking. Near the junction of the central pit with the south crater there had been an eruption from fissures that were still steaming, from which a great stream had flowed southwestward in the Kahuku direction; the lava had also poured down in cataracts into the south crater. Mr. Alexander observed about the summit for a breadth of a fourth of a mile from the crater many blocks, from fifty pounds to a ton in weight, of a "solid, flinty lava." The dimensions of the crater obtained by Mr. Alexander are stated on the map (Plate X.).

1887. Great Eruption in January and February, attended by Earthquakes. — In December, 1886, earthquakes became frequent in southwestern Hawaii. By the 12th of January the shocks averaged three a day. Between twelve minutes past two o'clock on the morning of January 17 and four o'clock on the morning of the 18th, 314 shocks were counted by Mr. George Jones in Kahuku, sixty-seven between the latter date and midnight, and three the following day. In Hilea, ten miles west, 618 were counted between two o'clock on the morning of the 16th and seven o'clock on the evening of the 18th.

On the night of the 16th, with the sudden increase in the

[1] Alexander, American Journal of Science, 1888, xxxvi. 35.

earthquakes, fires broke out at the summit near the small crater south of the summit crater, Pohaku o Hanalei (Plate I.), and in a few hours disappeared. The height of this first outbreak, according to Mr. E. P. Baker, was eleven thousand five hundred feet. On the 18th, at seven o'clock in the morning, — three hours after the cessation of the earthquakes, — an outbreak took place in Kau, north of Kahuku. The lavas came from a fissure about sixty-five hundred feet above the sea-level and twenty miles from the sea, and reached the sea at noon on the 19th, nearly four miles west of the flow of 1868. It extended the shore outward three to five hundred feet without making a cinder-cone on the sea-border. By noon of the 24th the flow had stopped, but the fires were still active along the stream.

At the outburst, as at the Kahuku eruption of 1868, the lavas were thrown up into fountains. The fountains were about eighty feet in diameter, and eighty to a hundred or more feet in height. They were photographed; and two of the views, representing the same part of the stream and one fountain, are shown on Plate XII. Mr. Spencer, who visited the source on the 20th, states that there were then fifteen fountains, and that the highest was two hundred feet; others make the height not over half this amount. The stream is stated to have flowed away bearing bowlders weighing tons, with explosions at intervals. During the first twenty-four hours the rate of flow was but a mile and a half an hour, and the stream made was of *aa;* afterward the flow was rapid, and the stream of pahoehoe.

The earthquake in Kau threw down walls that had a northeast and southwest direction, — the throw was to the southeast; and light wooden houses were moved eight or ten inches in the same direction or down the slope. The oscillations in Hilo were reported to have been from south-southeast to north-northwest.

On February 20 Mr. D. H. Hitchcock was at the summit,

TWO VIEWS OF A LAVA-FOUNTAIN AT THE ERUPTION OF JANUARY, 1887. (From photographs.)

and found the crater quiet, but vapors issuing from large fissures.

Kilauea was moderately active during the period of eruption, rather increasing in activity with its progress, but without evincing special disturbance or sympathy.[1]

In July, 1888, going from Ainapo to the source of the eruption of 1887, in Kahuku, about six thousand feet above the sea-level, Rev. E. P. Baker passed through regions of woods and grass, and saw seven running streams and three or four ponds of water. There had been heavy rains. The fissure of 1887, about four hundred feet above the place of outflow, was still giving out vapors. No deep crater marked the place of discharge.[2]

1887, *December* 29. — A letter from Mr. J. S. Emerson, dated Kohala, Hawaii, December 29, states that the view of the summit of Loa from that place indicates activity in Mount Loa. "Volumes of smoke and steam have been pouring out of the summit crater, but no glow or reflection of fire has been observed. . . . The summit is now heavily coated with snow." Another letter of April states that on March 29, 1888, the signs of activity at the summit had disappeared; the exact time of their cessation was probably early in February.

1888, *July* 18. — The summit was visited at this date by President W. C. Merritt and Rev. E. P. Baker.[3] The range of the thermometer for the day was: At noon, 62° F.; at seven o'clock in the evening, 40° F.; at eleven o'clock at night, 30° F.; at daybreak, 26° F. Mr. Merritt states that in the central pit of Mokuaweoweo, at bottom, a small cinder-cone was found not far from the eastern wall, and just south-

[1] The above is from the "Pacific Commercial Advertiser and Hawaiian Gazette" of Honolulu; American Journal of Science, 1887, xxxiii. 310.

[2] Baker, American Journal of Science, 1889, xxxvii. 53.

[3] Ibid., 1889, xxxvii. 51, 52.

west a pumice-cone in the midst of an *aa* flow, the summit of which was very hot and reddish from the action of vapors. In the southwest corner of the pit there was a cone (at F on map, Plate X.), from which vapors were escaping, and south of it, at *m*, a circular pit three and four hundred feet in its diameters by estimate, and a hundred and fifty to a hundred and seventy-five feet deep. In the walls of the pit, which consisted of the edges of layers of basaltic rock, one layer was forty to fifty feet thick, and vertically columnar in structure. The floor of the central pit had, as a whole, a slope from the southwest to the northeast, — confirming the view that the southwest part of the pit had been the seat of greatest activity, as it is in Kilauea. Southwest of *m* the outer wall of the central pit was cut through from top to bottom by two parallel fissures, which had a south-southwest direction, and thence pointed nearly toward the place of chief eruption of 1887. East of *m*, and near the wall in the direction of L, there were great numbers of small fumaroles, from which sulphur vapors were escaping freely, and large deposits of sulphur had been made about them. Near *h* two dikes, two to two and a half feet thick, intersected the walls, crossing one another at a small angle, the rock of which had a feldspathic aspect.

From a rough measurement the depth of the crater on the east side was made not over three hundred and fifty feet. If this small depth is sustained by careful observations, a great change of level had taken place since the survey of Mr. Alexander in 1885. Such a change might have been among the effects of the eruption of February, 1887. On the summit, to the south of the crater, Mr. Baker observed six parallel fissures, ten to twenty rods apart, having a course toward the place of eruption of 1887.

3. General Summary, with Conclusions.

The subjects connected with Mount Loa and the summit crater considered in the following summary and conclusions are the following: —

1. *The times and time-intervals of eruptions and of summit illuminations or activity*, with reference to (1) periodicity, (2) relations to seasons, (3) variations in activity since 1843, and (4) the changes in the depth of the crater.

2. *The ordinary activity within the summit crater.*

3. *Causes of the ordinary movements within the crater.*

1. Times and Time-intervals of Eruptions.

Question of Periodicity. — Commencing with the eruption of 1832, there have been nine registered eruptions of Mount Loa. Their times and heights of outflow, directions and lengths of stream, and relations to earthquakes are stated in the following table: —

	Reported Earthquakes.	Height of Chief Outflow.	Direction and Length of Flow.
1. 1832, June 20, 2–3 weeks	None.	Summit.	No outflow.
2. 1843, Jan. 9 to end of Feb., 1½ mos. .	None.	11,000.	N.N.W., 15 m.
3. 1851, Aug. 8, for 3 or 4 days . . .	None.	12,900.	W., 10 m.
4. 1852, Feb. 17 into March, 20 days .	None.	Little over 10,000.	E., 20 m.
5. 1855, Aug. 11 to Nov., 1856, 15 mos.	None.	12,000.	E., 26 m.
6. 1859, Jan. 23 to Nov. 25, 10 mos. . .	None.	10,500.	N. W., 33 m.
7. 1868, March 27, 16 days	Earthquakes.	3,000.	S., 10–11 m.
8. 1880, Nov. 5 to Aug., 1881, 9 mos. .	None.	11,100.	E., 30 m.
9. 1887, Jan. 18, 10 days.	Earthquakes.	6,500.	S., 14 m.

The intervals between these eruptions, reckoning (A) between their beginnings and (B) between the end of each and the beginning of the following one, are: —

	A.	B.
Between eruptions 1 and 2	10 years 8 months.	10 years 7 months.
2 and 3	8 ,, 7 ,,	8 ,, 5½ ,,
3 and 4	6⅓ ,,	6 ,,
4 and 5	3 ,, 6 ,,	3 ,, 5 ,,
5 and 6	3 ,, 5 ,,	2 ,, 2 ,,
6 and 7	9 ,, 2 ,,	8 ,, 4 ,,
7 and 8	2 ,, 7 ,,	12 ,, 7 ,,
8 and 9	6 ,, 2½ ,,	5 ,, 6 ,,

The eruptions above enumerated — that of 1832, perhaps, excepted — were great eruptions; that is, they had outside or subaerial outflows. But the history shows that at other times in the sixty-five years the summit of the mountain has been often brilliantly lighted, and surmounted with a column of clouds of great height, made apparently from the escaping vapors, which became a lofty column of light at night. These summit illuminations have been shown to be evidence on page 197, not merely of action in or about the crater, but decisively of a boiling or fountain-like activity in the liquid lavas, if not also of outflowing streams. The drifting of Pele's hair on such occasions thirty-five miles to Hilo is as good testimony to the playing of jets or fountains as a note from an observer at the summit.

Moreover, we have learned from Kilauea that these times of brilliant action within the crater may be followed by subterranean or submarine discharges when not by subaerial, and therefore that they are not always merely the flaring up and fading out of the crater-fires. They announce that *the top of the Mount Loa column of liquid lavas may be up to and in the crater*, or have its maximum length and be at serious work. even when no outbreak ensues.

The following table contains the times of these minor displays, as well as those of the admitted greater eruptions. In the table the latter are indicated by italics.

Dates.	Conditions at the Summit.
1. 1832, June 20.	Bright light at the summit, 2–3 weeks.
2. 1843, *Jan.* 9 *to late in Feb.*, — 1½ *months.*	Clouds ; January 10–17, bright light
3. 1849, May, 2 to 3 weeks.	Brilliant light, just after activity in Kilauea.
4. 1851, *Aug.* 8, — 3 *or* 4 *days.*	Bright light for three or four days.
5. 1852, *Feb.* 15 *to June*, — *about* 4 *months.*	Brilliant light for twenty-four hours.
6. 1855, *Aug.* 11 *to Nov.*, 1856, — 15 *months.*	Bright light at beginning.
7. 1859, *Jan.* 23 *to Nov.* 25, — 10 *months.*	Brilliant light at first.
8. 1865, Dec. 30, — 4 months.	Brilliant light for four months, varying ; at close, Kilauea increases its activity.
9. 1868, *March* 27 *to April* 12; *the flow* 4 *days.*	Bright light from March 27 to 30.
10. 1872, August 10 into September.	Brilliant ; a lava-fountain of 500 feet ; a tidal wave on the coast ; Kilauea very active.
11. 1873, Jan. 6, 7, — 2 days.	Brilliant.
12. 1873, April 20 to October, 1874, — 18 months.	Brilliant more or less for eighteen months ; in June and August, 1873, a lava-fountain, 300–600 feet.
13. 1875, Aug. 11, — one week.	Brilliant.
14. 1876, Feb. 13, — few days.	Brilliant.
15. 1877, Feb. 14, — few days.	Brilliant ; a submarine eruption.
16. 1880, May 1.	Brilliant ; a lava-fountain of 900 feet ; Pele's hair fell in Hilo.
17. 1880, *Nov.* 5 *to Aug.*, 1881, — 9 *months.*	Bright for a few days.
18. 1887, *Jan.* 16, — *ten days.*	Bright for a few hours.
19. 1887, Nov. 25 into Feb., — one month.	Vapors ; no light seen.

The table contains the dates of ten periods of summit activity or illumination independent of the great eruptions, — some short, but others prolonged for months, and varying greatly in brightness.

All these minor displays have taken place without initiating or announcing earthquakes.

It is obvious from the tables that the lengths of the intervals between the eruptions and the summit illuminations are too various, so far as now understood, to sustain the idea of periodicity.

Relation to Seasons. — The evidence of a seasonal relation appears to be beyond question. Out of the whole number (nineteen), five, counting that of 1865, occurred in January, three in February, four in March, April, and May, and one in June, — making thirteen in the first six months of the year. Of the remainder four commenced in August and two in November. Thus fifteen out of the nineteen took place in the

wetter season. Add to these facts those from Kilauea, mentioned on page 125, where the months given are March (?), January or June, May, May, October, April, April, March, and the number for the same months of the year becomes twenty or twenty-one out of twenty-seven.[1]

Full meteorological tables for a comparison of the months as to precipitation, both at the base and summit of the mountain, do not exist, and the discussion of this important question has therefore to be left unfinished.

The following notes on the snows of Mount Loa are from Mr. J. S. Emerson of the Hawaiian Government Survey : —

"The snow-cap of Mount Loa in general may be considered as making its first appearance in the early part of November, and as lasting until late into March. This is my impression from observations the past season, which I think has not been particularly exceptional. During the early part of November the snow-fall was quite light, and seemed to melt rapidly away at its lower edges. By the 25th there had been two heavy snow-storms, covering the mountain-top with a thick coat, which lasted all through the winter. The snows are usually the heaviest in the month of February, I think, though I did not see the mountain during that month this year. My last view of Mount Loa was on March 29, when I could just distinguish patches or streaks of snow on the more protected portions of the summit." [2]

The relation to barometric changes is an important subject for future study, with respect to which we have now no knowledge. There are also to be investigated variations in the amount of vapors over the active craters dependent on *hygrometric changes*.

In view of the above facts it is probable that if there is any periodicity in eruptions it is more or less dependent on meteorological cycles.

[1] This relation to the seasons, first recognized by Mr. Coan, is mentioned also by Mr. Green in his "Vestiges," etc., p. 332.

[2] Letter to the author.

Variations in Activity since 1843. — The copiousness of the subaerial discharges has diminished greatly since 1859. Before the end of that year, or in the seventeen years from 1843 to 1860, five of the eight great eruptions had occurred; and of the three in the following twenty-seven years only one — that of 1880–1881 — was of great length.

The frequent occurrence of the brilliant summit displays during the twelve years preceding the middle of 1880 is another striking fact. Six cases are reported; and one was prolonged, with small interruptions, for eighteen months.

The first of these displays occurred nearly four and a half years after the eruption of 1868. But Mr. Coan, the mountain chronicler, was absent in this country during one year in the interval, — from the spring of 1870 to that of 1871. After the summit display of August, 1872, they came at short intervals, their lengths from the end of one year to the beginning of another, reckoned in months, being five, three, ten, six, twelve. After February of 1877 there was the longer interval of three and a third years. Such short-period alternations seem to imply the recurrence after each of a subterranean discharge somewhere, if not a subaerial. The display of 1877 quite certainly ended in a submarine eruption, and probably that of 1872 (pp. 202, 197).

The Changes in Depth of the Summit Crater. — The changes since the year 1834, when the crater was visited by Douglas, have diminished its depth by at least four hundred feet, if we may trust — as we probably ought to do — his measurement "with a line and plummet," making it 1,270 feet. In 1840 Lieutenant Eld, U. S. N., of the Wilkes Exploring Expedition, made the depth on the west side 784 feet (p. 183), and in 1885 J. M. Alexander 800 feet (Plate X.).

We know nothing as to variations in the level of the floor after and before an eruption, and nothing as to the down-plunges which have followed discharges. The terrace-levels

situated at the north and south ends of the crater may mark high lava-levels just previous to some ancient eruption, but they antedate history; for Wilkes's map (p. 184) shows that they existed in 1840, very much as now. The map (Plate X.) by J. M. Alexander, which contains his "estimates" of the depths of the terraces or "plateaus" below the highest point or summit, makes the terrace at the south end on a level with the upper of the two at the north end, suggesting thus that the two may mark one of the high lava-levels of the crater. In addition, it places the bottom of the South Crater (D), and that of the pit in the upper north terrace or plateau (A′), at or below the level of the bottom of the central crater, favoring the view that all three parts of Mokuaweoweo are still in active connection; which view is sustained by the facts (1) that the fountain of May, 1880, was a South Crater fountain, and (2) that the pit A′ was formed since 1874, as it is not in Lydgate's map of the crater of that year.

2. The Ordinary Work of the Mount Loa Crater.

General Course of Action. — Although but few ascents to the summit crater have been made since the first by Douglas in 1834, and only five of these found the crater in action, there are still facts enough for important conclusions. The *cycle of changes* has been, beyond doubt, the same essentially as in Kilauea, — that is, when a discharge takes place: (1) the lava of the lava-column within the central conduit of the mountain falls to a level some distance below the crater (say one or more hundred feet), as a consequence of the loss by the outflow. Then begins (2) a rising of the lava of the column until it again shows part of its fiery top in the bottom of the crater engaged in its usual projectile work, and until finally it has reached a maximum height; and then follows (3) a new discharge, and another time of inactivity for the crater.

The Projectile Action within the Crater. — Projectile action in the Mount Loa crater is in strong contrast with that of Kilauea. Instead of the Kilauea feature of low jets suggesting ordinary ebullition, with only occasional throws to a height of one to two hundred feet, the descriptions of the summit action tell solely of fountains of clustered jets seventy-five to six and even nine hundred feet high, as if the height of the jets or the intensity of the action were proportional to the height of the lava-column. The four accounts of this activity — one in 1872, three in 1873, and one in 1880 — are alike in this respect. One of the three in 1873 describes the crater when the summit light appeared feeble from below, and the others when brilliant, and the former is scarcely less marvellous in its fountains. The evidence is almost conclusive that such fountains are of ordinary occurrence. This was the opinion of Mr. Coan; and Mr. W. L. Green, in view of his summit observations in 1873 and the reported facts of others, ascribes to all the periods of summit illumination "great fountains."

3. Causes of the Ordinary Movements within the Crater.

The Rise of the Lava in the Conduit. — The rise of the conduit lava may be safely attributed in part, probably a large part, as in Kilauea, to the quietly acting ascensive force in the lava-column.

The other volcanic agency of greatest prominence, as admitted for other volcanoes, is that of the *rising*, *expanding*, and *escaping* vapors. The vesiculating effects of the vapors as regards the Mount Loa flow of 1880–1881 have been already described on page 166; and it remains to consider —

The Cause of the High Projectile Action in the Summit Crater. — Higher projectile action in Mount Loa than in Kilauea through the escape of elastic vapors might come (1) from greater viscidity in the lava, or (2) from less specific

gravity of the material, or (3) from a larger supply of vapors. The first of these causes cannot be the right one, for greater viscidity should lead to high cinder ejections ; on the contrary, the lavas show that they are as mobile as the Kilauea lavas by the velocity of the lava-streams and all the attending phenomena, and more by the free play of the fountains. The second is set aside by the identity of the lavas in density, even to the occurrence of heavy chrysolite lavas with a specific gravity of 3·2.

If neither of these explanations meets the case, we have only the third to appeal to, — a greater volume of elastic vapors. It is, accordingly, probable that the cause which can produce *occasional* jets of one to two hundred feet in Kilauea is capable of producing the *prevailing* high jets or fountains of the summit of Mount Loa. The amount of work done there is ordinarily at least one hundred to a thousand times greater than in Kilauea; for the jets are five to ten times higher. But why should the volume of vapors in the lava-column be greatest at the summit ?

This difference in amount could not be a fact if the vapors within the slowly ascending lavas were from the profound depths that supply the lava, or even from depths much below the sea-level. For, under such circumstances, (1) the difference in the amounts carried up to the two craters would be small, since the rate of supply from below would be essentially uniform; and (2) the difference in the height of the columns would be more favorable to Kilauea, whose lava-column rises above tide-level but thirty-seven hundred feet, than to Mount Loa, nine thousand feet higher. The area of the floor of Kilauea exceeds that of Mount Loa.

But if fresh water from precipitation over the island supplies the vapors, then the difference in the heights of the lava-columns is greatly in Mount Loa's favor. A section of its lava-column at the sea-level may receive moisture during the whole time of its rise to the summit, a distance 3·8 times

that for Kilauea. The ratio 3·8 to 1 for the difference in supply of moisture to the columns would be too large on account of the little precipitation over the upper part of the mountain and the much less extent of surface in this part; but it may safely be put at 2 to 1, if not 2½ to 1. The ascensive movement in the Mount Loa lava-column may be somewhat more rapid than in the shorter conduit of Kilauea, provided the hotter central portion derives any upward thrust from the pressure of the cooler lateral portion, as suggested on page 168; and this cause would diminish the difference between the two as to the supply of vapor received, yet not largely.

The fact here apparently established — that only through waters from the island-precipitation could Mount Loa get its larger supply — affords new evidence that *the inland waters are the chief source of the vapors concerned in Hawaiian volcanic action.*

Is there any other Source of the Projectile Action? — The lava-fountains of the summit crater are so marvellous in size considering the density of the lavas, so near the incredible, that we naturally seek for other possible explanations.

Hydrostatic pressure is out of consideration, inasmuch as the fountains are at the summit of the dome, and at times throw their jets fifty to a hundred feet above the mountain's top, — over fourteen thousand feet above the sea-level.

Another source of projectile action has been suggested by Mr. Green, as briefly mentioned on page 175. In opposition to other writers on volcanoes, he sets aside the idea that vapor of water is concerned effectually in the projectile action even of Kilauea. The feeble amount of vapors observed by him over the fountain of the summit crater in 1873, and the general absence of vapors from the flowing lava-streams of 1859 and 1880–1881, besides other similar facts, have led him to his position on this point. He recognizes the fact [1] that great

[1] Vestiges of the Molten Globe, pp. 75, 162–167, 175, 272–278, 309, 314.

heaps and columns of clouds form over an active crater, and rise at times to a height of many thousands of feet; but accounts for these on the assumption that the heated current ascending from the active crater derives rapid accessions of air from either side, and this air, by being carried up to cold heights, yields the moisture by condensation, and so forms the column of clouds. Further, he finds a cause of some projectile action for the Kilauea lava-lakes and others in atmospheric air carried down by the descending lavas of the jets into the lava-lakes, — as the crests of waves carry down air into the sea; and for the rest of it, or that producing the crater-fountains like those of Mount Loa, he holds that the ascensive action in the conduit, after a time of quiet, suddenly overcomes resistance or stoppages that have come to exist in the conduit at depths below, and, as a consequence, the lavas, suddenly released, are thrown up in fountains, like the jets of mineral oil from an artesian boring.

Part of the argument as to the absence of vapors of water has already been met in the remarks on vesiculation, by showing (1) how extremely little moisture is needed to produce vesiculation, and (2) how much moisture hot air will dissolve and make invisible. It has also been stated (3) that if a lava-stream, flowing down Mount Loa, has but a single fountain-head, as is generally supposed, though not proved, nearly all the vesiculation must occur at the source, so that for this reason and the heated air above it, the lava-stream should be vaporless, or appear so, except where there are fissures below for additional supply.[1]

Further (4), direct observation proves that the vapors come up out of the crater. They often rise directly from the orifice of the crater, too low down for the air-current to have got into action; and in such cases there is an obvious source for

[1] Mr. Green states, as an exceptional case, that at one place on the Mount Loa flow of 1880–1881 the lavas spread into a large lake, and vapors rose from it in great amount. This is good evidence of the existence there of a local supply of lavas through a fissure.

the condensed moisture, and that is, the liquid lavas of the crater. Mr. Green expresses the fact well in the words:[1] "There is very often a large quantity of smoke seen to arise from the orifices of eruption, and this often spreads out in the higher regions of the atmosphere. There was a column, perhaps five hundred feet wide and ten thousand high, arising from the orifice of 1859 when we pitched our tent alongside it," — a point on the mountain ten thousand five hundred feet above the sea-level.

Further (5), the feeble amount of vapor observed by him in 1873 over the fountain in the summit crater, so unlike what had existed a few days before, may have its explanation in the dryness of the atmosphere at the time. The air is generally dry at the summit, but must have its phases of unusual dryness, during which an unusual amount of escaping moisture would, for this reason, become invisible.

(6) The summit fountain is a combination of jets, each of which must have had its initiating projectile act, and it continues for weeks and months; and this is at variance with the evidence from Kilauea, which makes the ascensive action very gradually and quietly lifting, instead of projectile.

Finally (7), the cold atmospheric air carried down into a lava-lake by the jets could generate very little projectile power. The air, on entering the lavas, would encounter a temperature near 2000° F. if not beyond it, and hence the expansion would cause expulsion, or a speedy escape, in spite of any currents or intestine movements that might exist in the boiling caldron.

For these reasons we may conclude that the old and generally accepted explanation which attributes the projectile action chiefly to water-vapor is not seriously invalidated by the ingenious suggestions brought forward by Mr. Green.

[1] Vestiges of the Molten Globe, p. 169.

Solfataric Action.

The escaping vapors produce incrustations of sulphur at the mouths of fissures in and about the crater; but owing to the intermittent character of the emissions, years often intervening between its periods as between times of eruptions, no accumulations of sulphur or of other solfataric products exist about the summit.

In the caverns of lava-streams, where the escape of hot vapors is sometimes long continued when they are situated over fissures, the same incrusting products have been observed as in Kilauea, among which glauber salt is sometimes abundant, as formerly in a cave near Kailua. Alum appears to be an unusual result in these basaltic regions.

C. ERUPTIONS OF MT. LOA AND KILAUEA.

In the following pages the subjects considered are: (I.) The Characteristics and Causes of Eruptions; (II.) Metamorphism under Volcanic Action; (III.) The Form of Mount Loa as a Result of its Eruptions; (IV.) The Relations of Kilauea to Mount Loa; (V.) General Volcanic Phenomena.

Under the head of Eruptions, the principal topics are: the Kinds; the Places of Outbreak; the Causes; the Characters of the Lava-streams; the Position and Origin of the subordinate Lateral Cones.

I. Characteristics and Causes of Eruptions.

Eruptions are of two kinds: (1) *Non-explosive eruptions*, or quiet outflows, seismically attended or not; (2) *Explosive eruptions*, or catastrophic upthrows. There are also combinations of the two kinds.

1. ORDINARY OR NON-EXPLOSIVE ERUPTIONS.

Kilauea and Mount Loa are alike, as has been shown, in (1) their mode of work; (2) the southward position, in the crater, of the point of greatest activity; and (3) the general features of their eruptions. But in amount of eruptive work the summit crater is far ahead of Kilauea, and, in fact, it leads the world. Kilauea has had but one subaerial outflow of any magnitude in the last fifty years, and that only twelve miles long. Mount Loa, on the contrary, although nearly thirteen thousand feet up to the bottom of the crater, has had in the same time only one of its eight less than twelve miles long, and several between twenty and thirty-five; and it has reached its height without a loss of eruptive power. It is reasonable, therefore, that Mount Loa should have most instruction to give about outflows.

Height and Position of Outbreaks.

The Height. — The place of outbreak of a Mount Loa eruption may have any height from the summit to levels far below the sea-level; and this "far below" may be (as the map on page 26 shows) 17,250 feet down, before reaching the actual foot of the eastern slope. The heights of known occurrence are mentioned in the table on page 217. The completion of the topographical survey of Hawaii, now in progress under the Government, will before long give more correct figures. The height of the source of the one Kilauea outflow, that of 1840, or rather of the spot where it appears to have begun, is, according to Wilkes, 1,244 feet above tide-level.

In each of the cases of eruption, fractures were made near the summit which extended down the mountain to the place of chief outflow, with only small discharges along them, when any. In some cases fissures have opened on the brink of

the crater and let out lavas; but all the large outflows of modern time have come from points a thousand feet or more below the summit.

Relations between the Positions of the Places of Outbreak and the Diameters of the Craters. — The course of the northern half of the longer diameter of the summit crater is about N. 35° E., and that of the southern half about N. 20° E. or S. 20° W., as marked on the upper and lower margin of Plate X. Four of the largest lava-streams of Mount Loa — those of 1843, 1852, 1855, and 1880 — and two others to the south — those of 1868 and 1887 — have their places of outbreak nearly in the line of the respective halves of *the longer diameter*. Again, three of the eruptions — those of 1851, 1859, and 1877 — broke out on the west side of the summit, nearly in the line of *the shorter diameter*, or between the summit and Hualalai.

There is here probable evidence of a dependence of the eruptions to some extent on the two great fissure-lines upon or about which the mountain's foundations were laid.

In Kilauea the direction of the longer diameter is about N. 50° E. – S. 50° W. The chief course of eruptions, as on Mount Loa, is marked by a line of fissures and ejections running west-southwestward in the direction of the longer diameter. But the large outflow of 1840, and the fissures leading to it, instead of pointing away from the crater, have a course nearly *parallel* to the longer diameter, but fifteen miles south of the Kilauea line. This is seen on the map (Plate I.), the stream being the one near the east cape.

Causes of Eruptions.

State of Readiness for an Eruption. — The *ordinary quiet* work of the craters has been shown to be carried on by —

(1) The ascensive force of the conduit lavas: producing (*a*) a slow rise in the liquid rock from depths below; and (*b*) a raising of the crater's bottom.

(2) The elastic force of rising, expanding, and escaping vapors: producing jets and fountains in the lava-lakes; overflows or ejections spreading the lavas over the crater's bottom; vesiculation of the lava, and consequent increase of its bulk.

Other causes have been mentioned as occasionally in action on page 169, but as not essential to the chief results.

After a season of this ordinary activity, with more or less gradual increase of intensity, a state of readiness for an eruption and its determining conditions have been reached. This has happened when the lava has risen, through these agencies, to what might be called *high-lava mark;* a level some hundreds of feet above low-lava mark or the low level occasioned by the preceding discharge.

Action needed for an Eruption. — After this preparation nothing is needed for an eruption but an agency of sufficient force to break the lava-conduit; for if broken seriously the lava will run out, and therein is an eruption or discharge.

Neither of the agencies carrying on the ordinary quiet work of the volcano has shown itself capable, during historic time, — that is, since 1822, — of breaking the lava-conduit for a discharge. The escaping vapors have spent their force mostly in making jets and fountains and feeble outflows within the crater; and still more quiet has been the work of the ascensive force. Eruptions have been a sequel to years of this quiet work, but not a direct effect of the action.

Agency of Earthquakes. — Earthquakes have often been considered an effective agent in eruptions. But during the past sixty-seven years only two of the eruptions of Mount Loa and one of Kilauea have been introduced, or attended, by noticeable earthquakes. The eruptive agent in both volcanoes has in general worked quietly, — "as quietly as the moon rises," says one writer without much exaggeration. The star-like light on Mount Loa has been followed soon by a stronger glow; and, accompanying this, a rising of clouds into heaps

and lofty columns. After a day, or two, or three, the summit light having disappeared, the flow has begun one, two, or three thousand feet below the top; and a line of light has then slowly lengthened down the mountain for twenty or thirty miles; and all this quietly. It is the grandest of volcanic work with the least possible display of force.

The facts connected with the two eruptions of Mount Loa and one of Kilauea, that were attended by earthquakes, merit special review in this place because they teach what earthquakes may do, and by what means. The three occurred in the years 1868 and 1887.

On a Friday in 1868, March 27, as stated on pages 89, 194, a light was seen on the mountain, and feeble earthshocks occurred. Only slight eruptions followed. Then, in accordance with the ordinary rule, these first fires at the summit disappeared. But the earthquakes increased in violence, — not about the summit, but far to the southwestward, within the lower three or four thousand feet of the mountain. And they continued increasing until that "terrible shock" of Thursday, April 2. Five days later, April 7, the lava burst out from an opened fissure at a point *twenty-three miles distant from the summit*, and only ten or eleven from the sea-coast. The reader should refer to the map (Plate I.), where the position of the outflow is given.

It is here manifest that the earthquakes had nothing to do with *preparing* for the eruption; they were too late for this. It is possible that the first break near the summit anticipated the first earthshock. But below, in the region of most violent disturbance, greater fissures were opened, the profoundest probably at the very time of that "terrible shock;" and as soon after as the subterranean passage could be made — about five days — the lava from the broken lava-conduit or reservoir made its appearance at the surface and hurried down the mountain to the sea. But at the sea-border and elsewhere the fissures were probably ahead of the lava, according to

Prof. C. H. Hitchcock, and gave it exit nearly all the way, occasioning their rapid progress seaward.

Here, then, it is clear what the earthquakes did to produce the eruption. They, or the cause generating them, broke a hole into the conduit, and the lava escaped. The lava of the conduit was not thrown into commotion or projected to great altitudes *at the summit;* instead of this it sank out of sight, following the rent to the surface far down the mountain.

These events were repeated almost precisely in the Mount Loa eruption of 1887. The locus of the outflow and of the earthquakes in both cases was far south in southern Hawaii, and the two streams followed near and parallel lines. The chief difference between them was in the higher outlet in 1887 by twenty-five hundred or three thousand feet.

The 1868 *earthquake eruptions of Kilauea and Mount Loa were coincident in time.* The earthquakes were the same identical earthquakes; and that "terrible shock" of April 2 was for each the special discharging-agent. Immediately after the shock, the fires of Kilauea, before unusually active,[1] commenced to decline; by night of that Thursday all the burning cones, by night of Saturday all the smaller lava-lakes, and by Sunday night the great South Lake had become extinct. And then, the lavas having run off, half the floor of the great crater of Kilauea sank down three hundred feet.

A genetic connection between the earthquake disturbance and the eruption cannot be doubted. The earthquakes came after the crater had reached a state of unusual activity, and hence could have taken no part in the preparation. They simply discharged the lava by breaking the conduit that held it.

[1] Dr. W. Hillebrand states that for two months previous to the eruption there were eight lava-lakes in the bottom of Kilauea; and until March 17, a very active blow-hole in the northwest corner, where "large masses of vapor were thrown off as from a steam-engine." On Thursday, April 2, after the earthquake, there were fearful detonations in the crater, and portions of the wall tumbled in; and then began the decline.

Moreover, the earthquakes which thus emptied Kilauea were of Mount Loa origin; they had their centre thirty miles or more west of Kilauea, and were made through the Mount Loa fires. It is a case, therefore, of one mountain-volcano accidentally discharging the conduit-lava of another. The work was simply a fracturing of the mountain in different directions, — for the island was violently shaken from the west side to Hilo, on the east coast; and in the general fracturing the two volcanic conduits were broken at once, an accident not likely to happen often.

It is also to be noted that *the earthquakes were of local or volcanic origin.* This is established by the fact that only two of the heaviest shocks reached westward to Honolulu on Oahu (p. 195); and these so feebly that they did not make themselves generally felt in that city. The depth of the oceanic depression between Hawaii and Oahu, which is only five hundred fathoms where least (between Hawaii and Maui, map, p. 26), was sufficient to stop off the vibrations.

Further, as in the Mount Loa eruptions, no increase of projectile action was occasioned in the crater of Kilauea by the earthquake disturbance; the lavas simply, in the quietest way, ran off, leaving the crater empty, still, and dark.

A mountain having within it two great regions of liquid lava thousands of feet in height, ten thousand feet or more in diameter, and each at a temperature above 2000° F., and with subterranean waters abundant, at least through the lower two-thirds of the altitude, is well fitted for the production of eruptive crises. It is remarkable that the eruptions of 1868 and 1887 are the only ones seismically occasioned, or attended, in the past sixty-five years; and, further, that in these eruptions, although among the most violent on record, the craters were wholly free from explosive action.

The violent earthquakes of 1868 and 1887 accomplished nothing so far as the eruptions were concerned that is not effected on Hawaii in four eruptions out of five without them.

The greatest of the eruptions have had no such aid. In the preparation for a discharge, the mountain has reached a critical state, because of the elongation upward of the fire column; it is then that the fracturing agency does its work; earthquakes are only a possible incident. With or without them, the conditions and results are the same; for vibrations necessarily attend fracturing, and earthquakes are simply the stronger or perceptible earthshocks.

The Rupturing and Ejecting Forces. — The chief cause of the rupturing is no doubt the elastic force of suddenly generated vapor. So far this is an accepted explanation. As to the conditions under which this vapor is generated, there is not so general agreement.

The facts show, *first*, that on Hawaii the vapors are not suddenly generated *within* the conduit; for, in the event, the lavas slink away from the crater, instead of dashing up wildly to great heights. If not generated *within*, it must be *without*, and the most probable region is that of the hot exterior of the conduit, or the hot rocks encasing the liquid column, or else fissures or local fire-places adjoining it. In this view the fracturing depends on the sudden access of subterranean waters to this outside region of great heat.

Secondly, the evidence proves that the force makes a fissure or fissures for the discharge of the lava without giving the waters entrance into the conduit. The pressure of the elastic vapor expends itself in breaking the sides of the mountain, and only under the most extraordinary circumstances is the water forced into the lava-column. The earthquakes of 1868 were an exhibition of the power generated; and hardly less so is the noiseless fracturing for the greatest of eruptions.

Some erupting action comes from hydrostatic pressure. But the fact that the fissures first open quite near the summit of Mount Loa is evidence that pressure from this source is the least efficient agent.

Why southwestern Hawaii should be especially liable to violent earthshocks in connection with its outflows is not wholly clear. But there are three significant facts bearing on the question : —

(1) The southern half of the longer diameter of the Mount Loa crater, and fissures from it down the mountain, point directly to the places of outbreak of 1868 and 1887, the probable localities of the earthquake epicentra of those years.

(2) The longer diameter of Kilauea, with a long line of fissures, having the trend S. 52° W., points nearly to the same region of outbreak ; so that the *two diametral lines, the Mount Loa and the Kilauea, there intersect.* (See map, Plate I.)

(3) These lines have long been common directions of fractures and eruptions, as shown by the old lavas of the surface as well as by existing lines of fractures.[1]

In eruptions the *ejecting* force may be feeble or null ; for the lava may flow out, when the source favors it, simply through gravity : but, in general, ejection is pushed forward, by the elastic vapors within the lava-column ; by vapors generated outside, like those producing eruptions ; and by hydrostatic pressure.

The first of these causes is the source of the high fountains in the summit crater ; and the summit effects indicate that it should have great propelling power at places of outflow. The fountains at the outflows have hitherto been attributed to hydrostatic pressure ; but the two causes must here act together, and it is impossible to say from present knowledge which preponderates.

Fountains attended the outbreak at the eruptions of 1852, 1859, 1868, and 1887 ; and it is probable that examination at other times would have added one or two to the list. The lengths of the lava-column (Λ) above the place of outbreak at

[1] This divergence between the courses of the longer diameters of the craters of Mount Loa and Kilauea comes up again for consideration in the remarks on the relations of the two volcanoes.

these eruptions, and (B) the reported heights of the fountains in feet, are as follows: —

	1852	1859	1868	1887
A	2500	3000	10,000	7000
B	200–700	300–400	200; 600?	80; 200?

Owing to the height of the column above the level of the outlet in 1868, ten thousand feet, the hydrostatic pressure should then have been greatest; the force from the vapors in the lava-column, least; and the friction in the very long passage-way from the broken conduit, the most obstructing.

The second source of ejecting and fracturing pressure mentioned above is the probable origin of the fractures which sometimes cut through the walls of a crater to the summit; and if the vapors producing the pressure are generated over a source of liquid lava, the fissures would necessarily become injected with lava which might flow out above, in a continuous stream, down the mountain. Cases of this kind about Kilauea occurred at the eruptions of 1832 and 1868, as mentioned on pages 56, 90; and Mr. W. T. Brigham and Rev. J. M. Alexander mention others, of uncertain date, about the summit crater.

Mr. Alexander speaks of a "cataract of lava" descending the walls into the crater from the summit; and farther south, of two other similar cataracts; and at the summit he found the deep fissure from which the cataracts had been supplied with lava, and ascertained that it had also poured out an immense stream northward upon the first plateau, and thence southward into the central crater. "On the southwest side of the crater there had been another eruption from fissures that were still smoking, and the eruption had sent a great stream southward toward Kahuku, and had also poured cataracts into the south crater from all sides." "The flows were from some of the highest parts of the brim;" and "from the brink there had been large flows down the mountain." "These outbreaks from fissures around the rim indicate that the lava

had rather poured into the crater than out of it; and also that it had flowed from such fissures in vast streams down the mountain side." These cases, perhaps, date from the eruption of 1880, the last that preceded Mr. Alexander's investigation of the crater.

Such events, if attending an eruption, belong to its very beginning, before the lava is drawn off from the crater. They may occur at other times; that they do so is not yet certain, except in a small way within Kilauea, about the lava-lakes.

Outflows and the Attending Circumstances.

The Source. — An outflow of lava may commence as a stream or as a fountain. In either case the pent-up vapors of the lava-column make their forcible escape with the lava; and a cone of solidified lava more or less scoriaceous is usually formed about the vent by the pericentric action. These cones are mentioned in the descriptions of all the outbreaks, not excepting that of 1880, which was visited by Rev. E. P. Baker. Large deposits of cinders, or a light scoria, are sometimes distributed over the adjoining region, and Pele's hair is also a common product; the former where the lava is thrown up in fountains and partially cools exteriorly as it falls (p. 187), and the latter from the action of either the fountains or the low jets.

The summit crater of Mount Loa, unlike Kilauea, is often left, after an eruption, with one or more cinder-cones on the bottom, the larger of them usually in the southern portion of the crater. They are probably made as the heat declines with the commencing retreat of the lavas.

Rate of Flow. — The great flow of 1852, so grand in the fountains at its source and twenty miles long, was finished in twenty days; this gives for its mean rate of progress a mile a day. The flow of 1859, thirty-three miles long, occupied only eight days, which corresponds to a rate of four

miles a day on a mean slope of one foot in fifteen. The thirty miles to Hilo in the stream of 1880–1881 took nine months; and the mean slope was one foot in thirteen, or about five degrees.

The general conditions in the flow of a great stream, its obstructions and modes of overcoming them, are well described by Mr. Coan on page 189. As to actual *rate* of flow, we want more precise facts. It is difficult to reconcile the facts stated on these points, and especially the various velocities attributed to the different portions of a flowing stream; for example, the reported rate in one of the tunnels of "forty miles an hour," with a rate for the front of the flow of "one mile a week." The difficulty is still great if we suppose the forty to be only ten, whatever the obstructions along the front. The conditions are those of a discharging faucet, and the flow below is that of the liquid after its escape spreading widely over a rough surface.

The many openings through the crust of a stream into the tunnels, which give out vapors and often have the shape of jagged cones, suggest the possibility that a fissure may exist beneath in these and similar places for the discharge of lava and vapors. But the idea that such fissures generally underlie a lava-stream (which I formerly thought probable) is opposed by Mr. Coan; and there are not facts to sustain it except for the Mount Loa stream of 1868 and the Kilauea of 1840.

The tunnels of a stream, made by a crusting of the surface while the lava continues flowing beneath, have a smooth, and in part a somewhat glassy or enamelled interior, with horizontal flutings and mouldings, which were made by the moving lava, as described on page 209. The small capacity of the tunnel entered near Hilo suggested the following queries: How much of the lava of a stream a mile wide runs in tunnels? Does the little width of the tunnel, and thereby of the supply stream, account for the difference of

velocity in the tunnels and at the front? If so, the exit should be as free as that from a faucet, or the arrangements would not work. How many such tunnels exist side by side? Does a single tunnel continue on for twenty or thirty miles as an uninterrupted lava-duct? We should infer that for a large stream the system of tunnels would become a very complicated one.

Whatever doubts exist as to the rate of flow, there is none as to the extreme liquidity of the Mount Loa lava, and its equalling if not exceeding that of Kilauea.

The Amount of Lava Discharged. — There are no data as regards the breadth or the depth of the streams, for a satisfactory calculation of the amount discharged. The depths might at many points be ascertained from the holes left by burned trunks of trees. We have two such observations from Mr. Baker for the stream of 1880–1881, but not enough for an estimate of the mean thickness. We can now only make a supposition.

The flow of 1852 was twenty miles long. If we suppose the mean depth of the stream to be twenty feet, and the mean width 5,000 feet, the amount of lava it contains would be 10,560,000,000 cubic feet. Supposing the lava-column to have the mean diameter of the central part of the summit crater, 9,000 feet, it would contain, down to a depth of 2,500 feet (the place of discharge for that eruption), nearly 160,000,000,000 cubic feet of lava, or fifteen times as much as was discharged. Accordingly, the discharge, if the above figures represent the whole amount, would have drawn off less than two hundred feet in depth from the lava-conduit; and a rise of two hundred feet again would have made the mountain ready for another discharge. The calculation is suggestive, though otherwise of little value. In addition to the other uncertainties we know nothing as to how much of a discharge passes off into subterranean cavities. The amount may be very large, for the great eruption of

Kilauea in 1832 has little to show over the surface of the island.

Whatever the amount of lava, or of height, that is lost by the lava-column at an eruption, it has taken, as has been shown, but a very short time, in several cases, to fill up again for a new discharge. I repeat here that after the eruption of 1852, which produced a stream twenty miles long, had closed, the lofty volcano was ready in only three and a half years for a twenty-six-mile flow, that of 1855; and in three and a half years more, for another still longer, that of 1859, thirty-three miles in length of stream, — which is brisk work for the great old mountain. According to these facts the lava-column had risen, after the eruptions, at the rate of at least one hundred feet a year, so as to reach again the bottom of the crater and be ready for another discharge.

Kinds of Lava-streams: Pahoehoe and Aa. — The ordinary smooth-surfaced lava-stream, the pahoehoe, needs here no further description. The *aa*-stream is less often seen in process of formation, and is more difficult to understand. With reference to an explanation of its origin, I repeat here from page 9 the characteristics of the typical kind (not of the

Portion of an Aa Lava-stream.

thinner streams that approximate to the pahoehoe), and reproduce also the sketch of a portion of one to aid the conception of its roughness; the reader's conception of it will be feeble at the best if he has not already had a view of chaos.

a. The characters of the cooled *aa*-stream: (1) a mass of rough blocks one foot and less to one thousand cubic feet in size, loosely piled together to a height of twenty to forty feet above the general level; (2) the blocks bristling with points, but not scoriaceous, and less vesiculate than most of the pahoehoe; (3) the material rather brittle, and consequently, when made up of small blocks or pieces, easily broken down to a flat surface by the natives for the site of a house; (4) often *aa* making part of a stream when the rest is pahoehoe, either of the two the chief part; (5) sometimes making one stream from a source, when another from the same source going off in a different direction is pahoehoe.

b. The constitution and condition of the *aa*-stream when in motion: (1) a mass of rough blocks outside, precisely like the cooled *aa*-stream; (2) the motion extremely slow, indicating a semi-fluid condition beneath; (3) a red heat often in front among the blocks; (4) fused rock seldom exuding; (5) the blocks of the upper part of the front, as the stream creeps on, tumbling down the high slope, owing to retardation at bottom from friction, and thus a rolling action in the front part.

The *aa* field, owing to its crevices and shaded recesses, retains moisture, and decomposition at surface early commences, which favors germination of seeds; and as I am informed by Mr. Baker, the stream often becomes forest-covered when the pahoehoe alongside remains bare.

One of the best published descriptions of an *aa* flow is that of Judge Hitchcock (p. 206), which says: "Along the whole line of the advance the stream, twelve to thirty-five feet in height, was one crash of rolling, sliding, tumbling, red-hot rock, no liquid rock being in sight; with no explosions, but a tremendous roaring, like ten thousand blast-furnaces all at work at once." Mr. Baker writes (letter of February, 1888): "I have stood by a wholly molten stream of lava which miles below was cooling into *aa*."

Under the restrictions of such facts the *aa* cannot be explained by referring it to simply a partial cooling of a stream and then a breaking up of the crust on a new accession of flowing lava, — a common explanation; for there is no evidence of a crust from surface-cooling analogous to that of pahoehoe. It is not dependent on the mineral constitution of the lava, for one and the same stream may take either condition; and adjoining fields near Punaluu, as the author observed in 1840 as well as in 1887, are at opposite extremes as to the amount of chrysolite.

The *first* conclusion we may draw, in view of the facts, and especially the abrupt transitions in a flowing stream from *aa* to pahoehoe and the reverse, and the independence in kind of lava, is that the difference must be connected with some condition in the region flowed over; and the *second*, that where the transition from one kind of stream to the other occurs, the conditions must be such as will allow of extreme liquidity in one part (the pahoehoe), and occasion imperfect liquidity or a pasty state in the other (the *aa*).

It follows from the size and rough character of the blocks of lava, *thirdly*, that in an *aa* stream the lava must have been subjected to some deeply acting cooling agency to have made a crust thick enough for blocks ten to twenty feet and more in dimensions, — far thicker than the crust over the tunnels in a pahoehoe stream. *Fourthly*, that the cooling was not from above downward, as in the pahoehoe, — for there are no remains of a pahoehoe crust in the true *aa* field, — but largely from below upward; and thence comes the absence of a crust and of the usual amount of vesiculation. There are no fragments of pahoehoe among the *aa* fragments.

These four conclusions appear to lead directly to a *fifth*, — that the region flowed over and making *aa* was one having more or less of subterranean moisture, since only moisture could produce the partial cooling required; not a superficial

stream of water that the lava could evaporate, and so put out of its way, but deeper and more widely spread moisture; and not too much for the quiet work of molecular imbibition, and thereby of cooling and fracturing, with sometimes a "tremendous roaring, like ten thousand blast-furnaces." The *aa* near Hilo observed by the author was over a valley depression, beneath which such an amount of moisture may well have existed. Another was along the foot of the meeting slopes of Mount Loa and Kilauea, west-southwest of Kilauea. But the observations were too brief to authorize a positive opinion as to the influence of the form of the surface in these cases; and in others, according to the descriptions, the surface covered by the *aa* is not always depressed.

There must be more or less moisture in the dark recesses of Mount Loa. The cold summit will find enough in the air to condense at most seasons; and the percolating rains must keep the recesses damp, and even make standing water wherever the rocky layers favor it. With subterranean moisture a hundred yards more or less beneath the broad lava-bed the generated vapors would ascend into and through the liquid mass, cooling it thus from below, — yet not so much the hotter bottom, which receives new supplies of lava, as the portion above. The part solidified would become shattered or broken up by the tearing steam and by contraction from cooling; and at the same time the flow at bottom would displace and tumble together the great and small masses, giving the pile height because of the jagged forms of the blocks and the cavernous recesses left among them. This view appears to meet the demands of the facts I have observed, and all others so far as they have been published. But I present it only as a suggestion.

On this view an *aa* stream is literally an arate or ploughed-up lava-stream, — a stream ploughed up from near its bottom, so that, although vesiculated, the surface vesiculation

fails, as was well shown in the stream of 1880–1881 near Hilo and in all the other cases the author has examined.

Dome-shaped bulges in a cooled lava-stream would naturally be common over the pahoehoe part of it, where the stream begins to pass to the *aa* condition; and this is well illustrated over Mount Loa.

The *lava-balls* mentioned on page 10 appear to be produced through the rolling movement in the forward portion of the advancing *aa* stream, due to friction at bottom.

Lateral Cones.

Lateral cones are a frequent result of eruptions on Hawaii and the other islands of the group, although the lavas are basaltic. They occur, as in other volcanic regions, along the courses of fissures, along a flow of lava where fissures for supplying lavas are underneath it, and also in and about the summit crater. Whether a lateral cone consist of lava-streams or of cinders (lapilli) depends on the supply of heat as well as of lava in the vent; and whether the cinders make cinder-cones or tufa-cones is determined by the supply of moisture connected with the eruption, much descending moisture giving a mud-like flow to the ejected cinders, whence the low angle and saucer-like crater of the tufa-cone. They are sufficiently described on pages 14, 22.

2. EXPLOSIVE ERUPTIONS.

All the eruptions of Mount Loa and Kilauea within the last sixty-seven years — the period of actual history — have been, as has been stated, of the *ordinary* kind, — that is, quiet outflows. At each the lavas of the crater have simply quit work and sunk out of sight; and the discharge thus begun, with the consequent down-plunge of the undermined floor, was nearly all there was of eruption so far as the crater was concerned.

But traditional history gives hints of an eruption in 1789 — a century back — of another kind, an *explosive* eruption; and the results are visible over the region around the crater of Kilauea, as already described. Similar evidences exist of an explosive eruption in the summit crater, as may be inferred from the descriptions of Mr. Brigham (p. 194) and J. M. Alexander (p. 211), as well as the earlier of Captain Wilkes, and also about the summit of Hualalai.

In the cases here referred to, the ejected material includes solid masses of the basalt, much of it very compact, and some of the blocks fifty to a hundred cubic feet in size. For such work, instead of a cessation of the ordinary projectile action of the crater and a quiet discharge of the lavas when the eruption began, there must have been an enormous increase of projectile power, with great rendings of the rocks within reach of the up-thrust action. The eruption was not a quiet outflow, but a catastrophic upthrow. Whether accompanied or not by an outflow of lava from Kilauea in 1789, is unknown.

Examples of explosive eruptions, of apparently similar character, from Tarawera in New Zealand, and Krakatoa, an island just west of Java, will make clear what is meant distinctively by an explosive eruption, as the term is used and briefly explained on page 23.

In 1886, in the Tarawera geyser region, after some earthshocks, a projectile eruption of terrific violence and incessant detonations began. Scoria and volcanic ashes or sand were thrown to a great height that drifted with the wind and covered the country thickly and far away with ashes, making darkness over a breadth of several miles all the way to the sea in the Bay of Plenty. The height, as seen from Auckland, a hundred and thirty miles distant, according to a measurement by Mr. Vickermann of the Survey Department of New Zealand, was forty-four thousand seven hundred feet. The eruption was ended and the clouds of dust gone in six

hours. The work was done so quickly and fiercely that no cinder-cones were made by deposits about the place of chief discharge. No outflow of lavas took place.

The accompanying map and explanations will make the remarkable Tarawera events more intelligible.[1] It represents

[1] The facts here given are from an account of the eruption by T. W. Leys, 56 pages, 8vo, with maps and other illustrations, Auckland, New Zealand, and the "Report" of S. Percy Smith, Assistant Surveyor-General, 84 pages, 8vo, Wellington. The height of the ejections above given is cited from the latter work, page 29.

the Tarawera geyser region, — its lakes, mountains, and other features. A small map to the left shows the northern New Zealand island and the site of Tarawera in the N. 35° E. volcanic line of Ruapehu, Lake Taupo, and White Island; and White Island is represented in its usual steaming condition in a sketch just above. The line of the eruption in 1886 extended in a N. E.–S. W. course from Lake Okaro through Mount Tarawera and Mount Wahanga. Lake Rotomahana at the time of the eruption was emptied and converted into a region of craters. This lake previous to the eruption had on either side a geyser basin, and one of the famous geyserite terraces of New Zealand, the "Pink Terrace" on the west (P. T. on the map), and the larger and more beautiful "White Terrace" (W. T.) on the northeast side, with the geyser Te Tarata at its head. The outflowing waters of Te Tarata, descending the gently sloping surface to the lake, had covered an area eleven and a half acres in extent with its siliceous (or geyserite) depositions, forming a descending succession of whitish cream-colored and almost porcelain-like terraces. A view of a portion of the terraces is given in the left upper corner of the map. At the eruption both of the beautiful terraces were buried in volcanic mud and ashes, a mud volcano displacing the geyser basin. A sketch to the left (from a photograph by Mr. C. Spencer) represents the region of the "great chasm," two hundred yards and more wide, made in the Tarawera range at the outbreak; and the map gives its position, and also the positions of the several centres of eruption along the region. The outer dotted line on the map encloses the part of the Tarawera region that was covered with volcanic ashes, mud, and scoria, and the inner the portion of the large area that was buried beneath mud; and the latter includes the buried villages of Te Ariki, Moura, and Wairoa, where there was destruction of life as well as a general burial of houses. Subsidences continued to take

place along the great opened fissures for weeks after the eruption had ceased.

At Krakatoa, in 1883, the projectile discharge was equally sudden, and far more terrible and destructive. The height to which the dust was carried was made by Professor Verbeck fifty thousand feet. It began in the early morning of one day, made day into night (by its ejections of ashes) for thirty-six hours, and left the sky clear by the close of the next day. Nothing is said of an outflow of lavas.

The earthquakes at Tarawera were not violent; they were felt to a distance of fifty or sixty miles only; and a dozen miles from Tarawera Mountain, at Rotorua, on the geyser plains, no shock was able to upset a chimney or jar down crockery from a shelf. They were manifestly local, and had their centre near the surface, — an effect, not a cause; and they thus prove that the immediate cause of the eruption was local. The facts as to the Krakatoa earthquakes are similar. The deafening roar in each was made chiefly by the violent projectile action, the incessant detonations, and the ragings and thunderings of a storm.

Such eruptions are of a wholly different cast from the ordinary outbreaks and discharges of Hawaii. The projectile agent must gain access to the conduit lavas to produce so extraordinary projectile violence.

The eruption of Tarawera Mountain was probably brought about by the opening of a fissure that let subterranean waters *into* the reservoir of lavas; for Lake Rotomahana, situated on the line of fracture, and only three or four miles distant, lost its waters, and probably in the process of supplying water for the projectile work. The volcanic mountain had been long extinct; but the widely distributed geysers and boiling springs were testimony to the existence of liquid lavas just below the reach of descending atmospheric waters. The geyser lakes of Rotorua and other localities became hotter during the night

of the eruption, and continued so afterward. Under such conditions an old volcanic mountain, perhaps hollow from former discharges, might be burst open again. Had the ingressing waters passed into the lava-reservoir *at a great depth* below the surface, the generated vapors would almost necessarily have added outflows of lava.

The volcano of Krakatoa was probably started into action by a similar incursion, but of marine waters.

In both cases there were enormous chasms and crater-like depressions made, with a loss of the old foundations and of the rocks that occupied the depressions. But the facts, while they include the projection of large stones over the vicinity, show positively that the stones were few compared with what would be needed to fill the great cavities left in the region. The explosive eruption threw to great heights fragments of the liquid lavas in the shape of scoria and sand or ashes, but did not blow off the solid rocks of the mountain. The disappearance of these and the making of the cavities are explained by the engulfment or down-plunge of material *to fill the space left empty* by the projectile discharges.

An *explosive eruption* of the kind described is, then, one in which the projectile action, instead of ceasing at the time of eruption, becomes enormously increased; in which the erupting agent, instead of being roused to action outside of the lava-conduit, gains access to its interior, and hence the terrific boiler-like explosion.

For further explanation I repeat that the *ordinary* activity of a volcano consists in the more or less high projection of cinders or of liquid lavas, with usually a great increase in the height as the crisis of an eruption approaches. In such action there is nothing of the explosive work above described; neither is it entitled to be called a state of eruption; it is only a state of activity. Stromboli is perpetually at work in the *ordinary* way, with great variations in activity, "exhibiting

the nature of volcanic action in its true light;" but it is not in "perpetual eruption;" no true eruption of this volcano, non-explosive or explosive, has been recorded in recent times. A volcano often gasps out its life in cinder ejections; for this is the meaning of the summit cinder-cones of Kea, Hualalai, and Haleakala. It is still true, however, that cases may occur in which it is difficult to decide whether the condition is that of ordinary activity or of true eruption.

The results of the projectile eruption of Kilauea, mentioned on page 41, need not be here repeated. We learn from the deposits made by it that the eruption began in bombarding style, — the projection of great stones to a distance of one to two miles, ranging to a height a thousand or more feet above the place of discharge, — and ended in a widely extended shower of scoria and ashes. The finer material, besides covering all the borders of Kilauea, spread for miles to the southeastward, southward, and southwestward. It constitutes, as I learn from Mr. Baker, the sand of the Kau "desert," and makes the bed for six or eight miles of an excellent carriage-road between the crater and the ranch nearly half-way to Keauhou.

The evidence that the great stones were from the throat of the lava-conduit, and not from the walls of the crater, consists in their comprising, both east and west of Kilauea, kinds not found in the walls, and also many blocks of lava whose cavities are lined with minute crystals of pyroxene and a plagioclase feldspar (as described by Prof. E. S. Dana on a following page), which are proof of subjection to long-continued heat. The walls of Kilauea are out of the reach of such up-thrust or projectile action.

The explosive eruption of the summit crater is of unknown date. As some of the ejected stones are from fifty pounds to a ton in weight, it was probably similar in character to that of Kilauea; but the facts need further study.

Explosive eruptions at Kilauea and Mount Loa are excep-

tional occurrences, as the well-stratified lava-made walls of Kilauea show. The summit crater, as described by visitors, has, like Kilauea, walls made of the edges of lava-streams, without intercalations of prominent beds of scoria or other fragmental material.

An *explosive eruption* of a *semi-volcanic* kind, half-way between volcanic and seismic in action, is described on page 23; and Japan has recently afforded a possible example, — it is the eruption of Baldai-san in northern Japan on the 15th of July, 1888. The following are the principal facts, from a memoir by Mr. Y. Kikuchi: [1] —

The volcanic mountain was essentially extinct, though there was a steaming fissure or fumarole. On the 14th the spring of a spa on the mountain became dry, but it was flowing again the next morning, — or that of the eruption. At seven o'clock on the morning of the 15th there were the first faint earthquake rumblings; at half-past seven, heavy shocks; at a quarter of eight, the eruption. A dense column of steam and volcanic dust shot into the air with tremendous noise; and fifteen to twenty explosions occurred, each of a minute or more, at which the clouds of steam and dust went to a height of four thousand to about thirteen thousand five hundred feet, which spread into a canopy of much greater height, making pitchy darkness over the region. The dust was drifted southeastward to the coast, sixty-two miles; and there the dust-covered area had a breadth of thirty-one miles. About the sides and base of the mountain there was a tornado of wind, steam, thunder, lightning, and falling dust and rocks, and for five minutes rain. The trees blown down lay with their heads away from the crater. The rocks fell mostly about the top of the mountain, but were carried down in a great land-slide, which the rain had evidently promoted, that

[1] Journal of the College of Science, Imperial University, Tōkyō, Japan, part ii., vol. iii.

devastated twenty-seven square miles and buried villages in the Nagase valley.

The action was of extreme violence; but in an hour the dust-shower had mainly passed, for in place of the pitchy blackness there was only the dimness of twilight on a rainy evening; and in five hours it had wholly ceased. The amount of dust on the leeward mountain-slope was less than a foot, and on the seacoast only traces of a film. There was no flow of lava; and the dust was not that from glassy lavas or scoria, but resembled the earth from powdered solid lava.

The shortness of duration and the character of the dust and absence of lava-flow led Mr. Kikuchi to conclude that no lava was concerned in the eruption, in which case it would merit the title of semi-volcanic or volcano-seismic.

But the fifteen to twenty explosions of about a minute each suggest a doubt on this point; because such explosions, in their high-projectile character and their apparent regularity of interval, are like those produced by the escape of large vapor bubbles from very viscid lava (p. 17). Admit the extreme of viscidity which the vapors could by accumulation break through, and the effects would be those of the Baldaisan eruption, and not essentially different from those of Tarawera. Whether this is the right view or not, the loss to the mountain — which is roughly estimated by Mr. Kikuchi at 2,782,000,000 tons — might have been due mainly to the down-plunge following the ejection. The projectile vapors would have expended their energies in work where generated, steamboiler-like; after passing into the air above they would have driven ineffectually against volcanic peaks of solid lava.

II. Metamorphism an Effect of Volcanic Conditions.

The projected rocks of the region about Kilauea are a prominent source of evidence as to metamorphism by means of volcanic heat, as remarked on page 178; and other facts of like import are derived from the lava-stream tunnels and caverns. The rocks referred to and those also of the lavas generally, as well as the cave-products, are described by Mr. E. S. Dana in a following part of this volume. I briefly mention here a few of the facts that have a special bearing on metamorphism.

1. The minute crystals in the cavities of the ejected masses, instead of being zeolites, such as exposure to the weather or to moderately hot vapors might have produced, are proved by Mr. Dana, as has been stated, to be identical with the anhydrous constituents of the lava. Minute transparent acicular crystals have given him the angles of pyroxene; white rhombic tables, the characters of labradorite; and besides, there are brilliant iron-black octahedrons of magnetite and tables of hematite or titanic iron. These are the constituents of the basalt, and all of them, except the less constant one, chrysolite.

2. The caves and tunnels of Kilauea and of the Mount Loa lava-stream of 1880–1881 have been described as affording stony stalactites, remarkable for their slender pipestem-like size and form, some of them twenty to thirty inches long; yet these stony stalactites are essentially identical in constitution with the rock of the lava-stream, even to the laths of labradorite, as was suspected at the time of the visit to the tunnel, and as has been proved by the microscopic investigation of Mr. E. S. Dana, who found also that the crystals of the cavities are of pyroxene and labradorite as in the ejected blocks.

The origin of the stalactites of the tunnels and their

crystallizations is due, as I state in my "Expedition Report" (p. 201), to "the action of steam on the roof of the cavern." In the case of the tunnels the flowing lavas left behind a chamber filled with superheated steam, and under its action the solution and recrystallization went forward.

This reproduction of the basalt and the making of the crystals in geodes, or as linings of fissures, are examples of metamorphic work. It is metamorphism of the *crystallinic* kind,[1] — the same which takes place when a feldspathic sandstone is converted into granite or granulyte, or when calcyte is changed into marble. It is simply a reproduction of the basalt by superheated vapor.

3. The ejected blocks about Kilauea instruct us on another point of much geological importance. They show that the throat of a volcano is necessarily a region of metamorphic action. It is a region of continued heat; and heat always works change when moisture is present. The special results of this conduit metamorphism at Kilauea are described in the chapter on the rocks. The minerals made are, as in the stalactites, only the minerals of a basalt or doleryte, as augite, labradorite, magnetite, hematite; but they are put in groups of crystals in cavities and through the mass of the rock. Under like conditions, an Archæan limestone or other Archæan rock containing chondrodite, spinel, vesuvianite, scapolite, anorthite, nephelite, biotite, might lead to the production of recrystallized chondrodite (humite), spinel, vesuvianite, scapolite (meionite), anorthite, nephelite, biotite (or meroxene) as metamorphic results; and in just the situation where an explosive eruption might detach masses and bring them up to the light. It is noteworthy that the above minerals of the ejected blocks about Somma — which have long been regarded as throat minerals of Vesuvius crystallized by the volcanic heat, as held by Scacchi — are

[1] "On Terms applied to Metamorphism," American Journal of Science, 1886, 3d series, xxxii. 70.

kinds that are characteristic of Archæan rocks and especially of an Archæan limestone, rocks which may underlie the later limestones and other strata. There is little assumption, therefore, in saying that some of these crystallizations illustrate specifically crystallinic metamorphism, though others may be of the metachemic kind, that is, products of chemical change.

III. Form of Mount Loa.

Mount Loa differs from most volcanic mountains in having a double curvature in its profile, convex above and concave below, owing to the flattening and widening of its summit and the spreading of its base. It is the broad flattened summit which gives so vast bulk to a mountain of its altitude. In accordance with the principles illustrated on page 11, the dome-like shape has evidently been produced by the very work that has been going on during the last sixty-five years,— eruptions not from the summit, but from points one sixth to one eighth of the height from the summit. The top has thus been widened until it is almost a plane surface for a distance of one to two miles. At the same time there have been basal eruptions tending to spread the base above the sea-level. This effect is very marked to the southeastward of Kilauea.

Owing to the nearly complete absence of cinder-ejections, the summit of Mount Loa fails of the most common means of growth in height with tapering top; and this is a prominent source of the difference between it and most other volcanic mountains. Mount Kea secured its greater height and tapering top by the cinder-ejections which ended its period of activity.

Another cause tending to modify the shape of the mountain is that producing fractures and subsidences. Its effects are seen about the great craters, and still more pronounced about the borders of the island. The former action aids in

making summits broad and flat, while the latter works directly against the widening of the coast region. It makes the greatest fractures *nearly parallel with the coast, and drops the coastward block;* it thus tends to shorten the radius of that part of the mountain, and put precipices into its profiles, *increasing thereby the mean slope.* Two such walls in southern Hawaii cross the road between Keauhou and Kilauea, one about a mile and a half from the coast and the other three miles; they are marked features before the traveller in his ride from the coast to the volcano. These faultings seem to be a reason for the concavity in the southern coast-line from Keauhou westward, and for the short distance in that direction from the summit to the coast. Other great fault-planes exist; but the government map of the island should be completed before the facts can be satisfactorily discussed.

The following are the mean slopes of Mount Loa from the summit along different radii. The distances made the basis of the calculations are taken from the Government map.

S. S. W. to the southern cape	1 : 13·1 = 4° 22′
S. E. by S. to the indented Kapapala shore	1 : 9 = 6° 20′
S. E. to foot of slope W. of Kilauea	1 : 9·12 = 6° 15′
E. N. E. to shore at Hilo	1 : 14·86 = 3° 51′
W. by S. to western shore	1 : 8·11 = 6° 43′
N. by E. to plain between Loa and Kea	1 : 9 to 1 : 10 = 5° 50′ to 6°

In a circle of five miles around the summit crater the mean slope is about three degrees; the mean depression to the eastward at the perimeter of the circle is about fourteen hundred feet. It is interesting also to note that the slope of the eccentric cone of the bottom of Kilauea from Halema'uma'u northeastward — a result of the outflows of the Great Lake in 1885 — is about 1 : 50 or 1° 9′.

From Kilauea to the eastern cape, twenty-eight miles, the slope is 1 : $36\frac{1}{3}$ = 1° 35′.

The fact that Mount Loa as well as Kilauea was made over a great fissure has given an oblong and approximately elliptical

or ovoidal form to all the upper contour lines of Mount Loa. Further, the bend in the longer axis of the summit crater, making the concavity to the eastward, is also expressed, according to the large Government map, in the form of the upper part of the dome.

At what period in its history Mount Loa left off superfluent discharges and took to having only the *effluent*, or those through fissures, it is impossible to say. But as the walls both of Kilauea and the summit crater are made up of the edges of lava-streams to the very top, it would appear that summit overflows from the crater may have continued in each to a comparatively recent time. It is remarkable that the north and west walls of Kilauea, which show well the stratification from top to bottom, have almost no intersecting dikes.

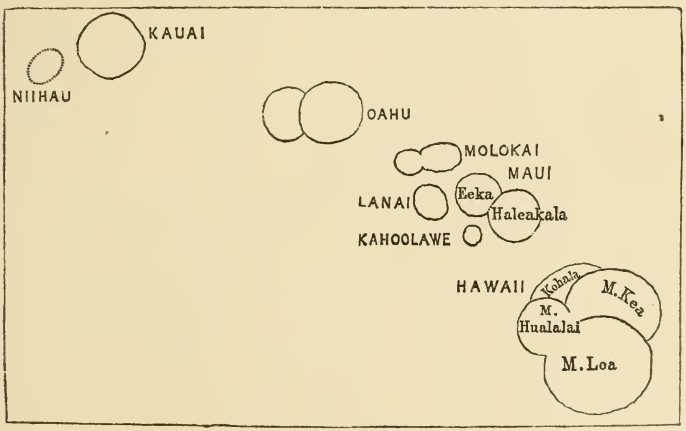
D. RELATIONS OF KILAUEA TO MOUNT LOA.

The position of Kilauea "on the flanks of Mount Loa," ninety-five hundred feet below the level of the summit, plainly *suggests* the idea of its later and dependent origin. If the two were begun at the same time, why, it is naturally asked, should not Kilauea have approximately the same size as Mount Loa? With the same time to grow in, and a distance between the two nearly equal to that between Kea and Loa, and a crater as large and still active, would it have stopped at less than one third the height, and have raised its summit only three hundred feet, at the best, above the Mount Loa slopes?

Several of the islands — Oahu, Molokai, Maui, and perhaps also Kauai — consist of two volcanoes united at base, or are volcanically twins; and Hawaii is a double twin, one couplet consisting of Kohala and Kea, and the other of Hualalai and Loa, *provided* Kilauea is subordinate to Mount Loa. In all

the twins the *eastern* of the two combined volcanic mountains is the larger. But Kilauea, although the eastern on Hawaii and the easternmost of the whole group, is one of the smallest. The greater size of the eastern volcano in a couplet has come from its continuing longer in action; and this is proved not simply by the size, but also by the evidence of long extinction, and therefore long exposure to denuding agents, in the western mountain. There is other evidence, also, in the fact that the slopes of the western of the mountains in each twin island are partly buried by the more recent lavas of the eastern, — Kohala by those of Kea, western Oahu by those of eastern. The order in time of extinction thus derived, which my "Report" presents, is as follows: —

1. Kauai.
2. Southwest Oahu.
3. Western Maui.
4. Kohala, on northwest Hawaii.
5. Northeast Oahu.
6. East Maui.
7. Mount Kea, Hawaii.
8. Mount Hualalai, Hawaii.
9. Mount Loa and Kilauea.



Here, again, the system seems to require that Kilauea should be made an appendage to Mount Loa. The above diagram is drawn to show these relations of the constituent

volcanoes.[1] Kea and Hualalai are made in it to spread too far over Kohala, the central region of which should have been left uncovered; but the general idea conveyed is right.

On these grounds the conclusion was drawn by the author in 1840 that Kilauea originated over a great fissure made at some Mount Loa eruption.

The close relation of the two volcanoes is made evident, further, by the recent investigation of the rocks reported upon beyond.[2] Prof. E. S. Dana's examinations have found the rocks, so far as studied, to be the same kind of basalt in mineral constitution and in all details of composition; as high in specific gravity; as varied in the proportions of chrysolite from apparently none to nearly half chrysolite; as varied in texture from the lightest scoria to the compact kind in which only microscopic vesicles are distinguishable when any; as generally free from glassy portions, glass being rarely distinguished in even the basalt of the most recent lava-streams; and as subject to the alteration to feathery forms of augite.

This conclusion is not accepted in the report of Mr. W. T. Brigham, Capt. C. E. Dutton, or Mr. W. L. Green.

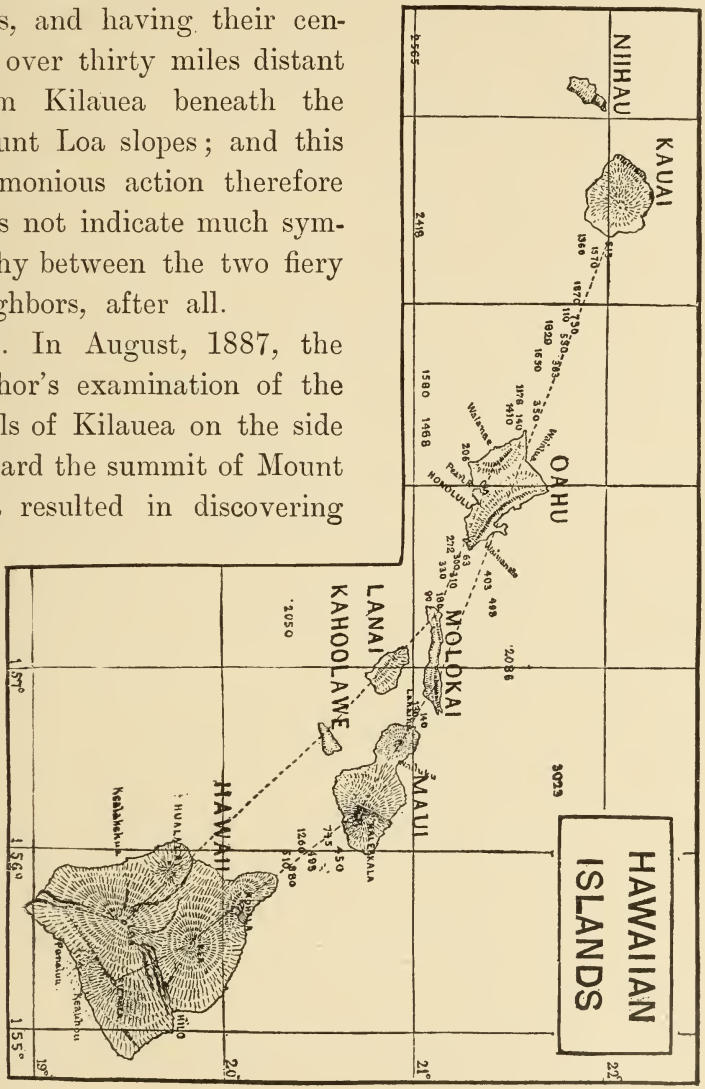
1. The apparent independence of action in Kilauea is one of the opposing arguments; and it is a strong one. There is commonly no sympathy in their movements, although both have craters of unusual magnitude which are in frequent eruption and essentially in continuous activity, and although the open vent of Kilauea with its boiling lavas is but 3,600 feet above the sea-level (in 1840 but 3,000 feet) against 12,900 for the Mount Loa crater. They have had some nearly simultaneous eruptions; but the larger part of the greater eruptions of Mount Loa have taken place while the lava-lakes of Kilauea were in a state of undisturbed ebullition. There

[1] Exploration Expedition Report, p. 283.

[2] Page 318.

was remarkable harmony of action in the earthquake eruptions of the two in 1868; but it has been shown that the earthquakes which set off Kilauea were of Mount Loa origin, made through Mount Loa fires, and having their centre over thirty miles distant from Kilauea beneath the Mount Loa slopes; and this harmonious action therefore does not indicate much sympathy between the two fiery neighbors, after all.

2. In August, 1887, the author's examination of the walls of Kilauea on the side toward the summit of Mount Loa resulted in discovering



no great dikes or other signs of former dependence on Mount Loa. This evidence is not of great value, because the wall now exposed to view may be far inside of the

wall of the greater original crater, just as the wall of the "lower pit" of 1840, which was in general without dikes, was inside of the corresponding wall of 1832 and 1823, and of the outer wall of the crater for each of these periods.

3. The distance between the craters of Mount Loa and Kilauea is about the same that exists between the other great volcanic centres of the islands. But this argument, urged by Mr. Green, is indecisive, especially in view of the small height of Kilauea.

4. A new argument may be derived from the relation of Kilauea to the *two parallel ranges of islands constituting the Hawaiian group*. These ranges are indicated on the accompanying map by the lines connecting the islands. The northern, or "KEA range," includes northeastern Oahu, eastern Molokai, eastern and western Maui, and, on Hawaii, Kohala and Kea; the *southern*, or "LOA range," comprises southwestern Oahu, western Molokai, Lanai, Kahoolawe, Mount Hualalai, and Mount Loa, with Lua Pele (or Kilauea) on the flanks of Mount Loa.[1] The Loa and Kea ranges have a mean trend of about S. 60° E. To the eastward the line of each range inclines increasingly to the southward. The northern, in its course from Maui through Kohala to the summit of Kea, becomes S. 45° E. in trend; and the southern from Kahoolawe to Hualalai and the summit of Mount Loa has nearly the same course.

Now, the line of the northern or Kea range, if continued on with only a little more southing, *strikes Kilauea;* while that of the southern points southward far away from it. *Kilauea appears, therefore, to belong to the Kea or northern range*, and not to the Loa or southern range; and if so, it is not an appendage to the latter range, or to Mount Loa, one of its volcanoes.

There is seemingly a "clincher" to this argument. The

[1] Exploring Expedition Geological Report, p. 157.

great craters are generally situated over the intersection of two fissures, one of which is the course of the range of islands and the other transverse to it, as stated by Mr. J. M. Alexander.[1] Now, the line of the Kea range strikes Kilauea very nearly at right angles to its longer diameter, in accordance with this rule. Further, the line of the Loa range, or better a line from the summit of Hualalai, strikes Mount Loa precisely in the same way. This coincidence, which the map well shows, seems therefore to prove that Kilauea belongs to the Kea range and not to the Loa. The substitution of a line from Hualalai for that from Kahoolawe is reasonable, because the fissures over which the Hawaiian volcanoes were formed were probably independent for each island, though conforming to the general system. The summits of Kea and Loa are corresponding points in the two ranges, and Kilauea is an advance of one stage beyond Kea in the Kea range; it is owing to this that the longer diameters of the Loa crater and Kilauea make an angle with one another of about 32°. It is interesting to note, also, that the longer diameter of the crater of Mount Loa, or especially its southern half, points to the top of Mount Kea; and that a line from Loa to Kea is nearly parallel to one between Hualalai and Kohala; so that the parallelogram enclosed has angles nearly of 70° and 110°.[2]

[1] American Journal of Science, 1888, xxxvi. 38.

[2] Mr. W. L. Green, in his "Vestiges of the Molten Globe," brings forward a theory for the origin of the general features of the globe, which supposes its deformation from contraction on cooling to have developed feature lines crossing at angles of 60°, — a "tetrahedral symmetry," — and subordinately to these other lines at right angles to the sides of the triangle. His map of the Hawaiian Islands, which is covered with triangles, represents one of these lines as meridional, and one accordant, consequently, with the mean trend of the group, or nearly so. On page 147 of his work, it is stated that confirmation of his hypothesis is seen in the fact "that the direction of the longer axis of the elliptical craters of Mokuaweoweo and Kilauea is N. 30° E." But the facts appear to be that the longer axes of the two craters diverge 32° in direction, and that of Kilauea has nearly the course N. 52° E. Moreover, the trend of the island volcanoes of the group varies greatly in going from one end of the range to the other; and in this the Hawaiian is like other ranges over the ocean.

Notwithstanding the independence of Kilauea, there may still at times be evidence of some sympathy; for the two great active lava-columns are only twenty miles apart.

The evidence does not make it certain, however, that Kilauea originated as early in the history of Hawaii as either Kea or Loa; for the original fracture extending in that direction from Kea may at first have been sufficient only to let out a flood of lavas, and subsequently have been further opened and crossed by a greater fissure, so as to produce over it the permanent Kilauea vent.

5. Whatever the fact as to the relations of Kilauea and Mount Loa, I believe they still sustain my old conclusion that volcanoes are not safety-valves;[1] for "if while Kilauea is open on the flanks of Mount Loa, lavas still rise and are poured out at an elevation of ten thousand feet above it, Kilauea is no safety-valve even for the area covered by the single mountain. Volcanoes are indexes of danger; they point out the portions of the globe which are most subject to earthquakes." The safer place is somewhere else. And among volcanic mountains, one that is really dead is a preferable neighbor to the volcano that has been smouldering from time immemorial. For the emission of heat by hot springs, geysers, or fumaroles within a dozen miles is pretty good evidence, as at Tarawera, New Zealand, that liquid rock is at no very great depth below, — too deep to receive from descending waters the moisture that may contribute energy to the fires and produce volcanic activity, but not too deep to be opened on an extreme emergency, so as to give entrance to a flood of waters for the most terrific of eruptions.

[1] Exploring Expedition Report, p. 221.

E. CONTRAST BETWEEN MOUNT LOA AND VOLCANOES OF THE VESUVIUS TYPE.

The marked contrast between volcanoes of the Mount Loa and Vesuvius types based on the liquidity of the lava, making Mount Loa discharges to be almost solely outflows and those of Vesuvius both upthrows of cinders and outflows of lava, has been sufficiently explained on page 143. With this exception, the contrast as to their eruptions as well as to their ordinary action is far less than is generally supposed.

There is no reason to regard the forces as different in kind or mode of action. If the outside waters gain slow access at depths below to the lavas for the ordinary action of a volcano in Hawaii, they can at Vesuvius; and the force from the escaping vapors that in this ordinary action will make jets of lava of thirty to six hundred feet will make jets of cinders of far greater height. Moreover, as the erupting force at Mount Loa in non-explosive eruptions is not due to vapors inside the lava-column, since it does its chief fracturing part-way down, and sometimes far down, the mountain instead of about the summit, and causes a quiet condition in the crater instead of violent action, so it is essentially at Vesuvius. In *explosive* eruptions at Vesuvius, on the contrary, the explosive force may be due to vapor-generation inside of the lava-caldron, the projectile action being vastly increased, as at Tarawera in 1886 and Krakatoa in 1883.

As the observations at Vesuvius of Scacchi [1] and others have shown (and my own two visits to Vesuvius, one just before an eruption, enable me to appreciate), high-lava mark in the volcano, or that of readiness for a discharge, is attained in the same way essentially as in Kilauea. After a down-plunge fol-

[1] Scacchi, A., Eruzione Vesuviano del 1850 e 1855, Napoli, 1855, in which the changes from 1840 to 1855 are carefully described.

lowing an eruption (as a result of the undermining), leaving the crater hundreds of feet deep and the upper extremity of the lava-column at a still lower level, work again soon commences, provided the lava-column were not so profoundly cooled off by the aggressive waters and vapor-generation as to be left too deeply buried. For a while the fractures in the bottom of the crater emit only vapors. Later, projectile action begins at one or more points, making conical cinder-deposits by the pericentric action, with now and then an addition to the inside accumulations from small outflows of lava about the bases of the cones or from their vents. The throws of cinders and flows of lava are kept up at irregular intervals, and the level of the floor rises. After the height within has become much increased, small fissures occasionally open through the outside slopes and let out some lava; but the ejections are mostly retained inside, except in the later period of progress, when some of the high-thrown cinders may fall over the outside of the mountain or drift away with the wind. Years pass, and finally the crater's bottom, bearing a large cinder-cone, or more than one, reaches that high level in which it becomes actually the summit-plain of Vesuvius; and the fires are visible in the cracks of the plain, because the liquid lavas are not far below it.

The author would refer the reader to a cut representing Vesuvius in the condition here described, contained in his "Text-book of Geology," made from his sketch in 1834, and to a paper in the "American Journal of Science" for 1835.[1] At his visit of that time he found the summit of Vesuvius a plain, — the *altopiano*, — with a small active cinder-cone near its centre. Only five years before, in 1829, the crater was reported to be two thousand feet deep, — "an immense and frightful gulf," [2] as viewed from the narrow margin. In the short interval high-lava mark had been reached. A red heat

[1] Vol. xxvii. (1835), p. 281.

[2] Wines, Two Years and a Half in the Navy.

existed ten to twenty inches down in many fissures over the plain; and at one place a stream of lava, four to five feet wide, emerged and flowed away down the mountain. But the floor was safely walked over, and the small spiteful cinder-cone was ascended, the work going on quietly, as at Kilauea. The mountain was charged, and a month later, in August, a great eruption occurred, the lava flowing eastward far toward Torcigno. M. Abich, — who was then, as he reports, studying the volcano, — after describing the top plain and its cinder-cone as seen by him before the event, states that at the eruption that platform of lava *subsided* and opened to view the interior of the large cone.[1]

Thus the processes are, as in Kilauea: (1) filling; (2) discharging; (3) collapsing.

How far the ascensive force in the lava-column contributes to the change of level in the floor of Vesuvius nobody knows. The question has hitherto hardly been considered. It probably does its part; for the liquid lava rises with the rising floor, following it closely.

With the column of liquid lava thus lengthened, making the mountain ready for a discharge, the danger of catastrophe is great for the same reasons as at Kilauea. But the danger is greater than there. It is greater because the forces from vapor-generation and hydrostatic pressure have a weaker mountain to deal with, — one that has steeper sides, and therefore thinner walls to the lava-caldron, and walls that are partly cinder-made. It is greater because also of the nearness of the lava-column to the sea, the distance being only four miles, while in the case of Kilauea it is over nine miles, and in Mount Loa over twenty; so that at Vesuvius water from two sources, the sea and the land, is close by.

Causes that produce earthquakes may make a rent in the Vesuvian lava-conduit that will let in water for an *explosive* eruption; but usually it opens the way, as at Mount Loa, for

[1] Erlaut. Abbild. Vesuvius und Aetna, Berlin, 1837.

a comparatively quiet escape of lava, however disquieting the event may be to deluged villages.

The loss by upthrows and outflows tends to produce a sinking or down-plunge of the floor of the crater, and some fall of its walls to the new bottom, as in Kilauea. At the Kilauea eruption of 1886 the outflow drew off the lavas of a lava-lake half a mile in diameter; the crust of lava that covered the borders of the lake, along with portions of the walls, consequently sank down, and the cavity or crater left by the discharge was half a mile across and between five and six hundred feet in depth. This is little different from the ordinary event in Vesuvius, except that the loss by the discharge at Kilauea is almost solely by outflow, and no high, weak-sided cone surrounds the vent to suffer from the disaster. It is true that the Kilauea lava-lake in the eruption just referred to occupied only a small part of the great crater. But its diameter was as large as the lava-caldron of Vesuvius has been before any of its modern eruptions; and the movements in the lake were the same that would take place were all Kilauea one great lake. "At the eruption of May 31, 1806," says Signor G. Zorda, "a considerable part of the summit fell into the volcanic abyss;" and facts enough are reported to show that the same took place at the grander eruption of 1822. But in the smaller eruptions of Vesuvius the *altopiano* often undergoes little change, because the undermining is not sufficient for more; and after a while cinder-eruptions may be resumed; consequently after such eruptions, as Scacchi observes, the height of Vesuvius may become increased. This, again, is parallel with the facts in Kilauea.

Explosive eruptions might prove much more disastrous to a Vesuvian cone than to one of massive Mount Loa style; but not because the explosion has the power of blowing off the mountain's summit, — which failed to happen at Tarawera in 1885, although the vent was closed, and

is not a possibility when the vent is an open one, — but chiefly because a steep-sided mountain is likely to lose more in height than a broad lava-cone from the same amount of undermining.

II. ISLANDS OF MAUI AND OAHU.

The subjects prominently illustrated by the islands Maui and Oahu are: the conditions of extinct volcanoes in different stages of degradation; the origin of long lines of precipice cutting deeply through the mountains; the extent and condition of one of the largest of craters at the period of extinction; and the relation of cinder and tufa cones to the parent volcano.

A. ISLAND OF MAUI.

The accompanying map (Plate XIII.), reduced from the recent large Government map,[1] shows the general features of the island of Maui.

(1) The volcanic mountain of East Maui, Haleakala, 10,032 feet in height, having at summit a crater 2,500 feet in greatest depth and twenty-three miles in circuit.

(2) The abrupt depression of Kipahulu, to the southeast of the summit, surveyed, but not yet geologically studied, which looks as if it were the site of another great crater.

(3) The slopes of eastern Maui, little gullied by erosion, but most so on the side facing northeast, — the windward side; and here the longest valleys scarcely reaching to the summit.

(4) The mountain of West Maui, Eeka, a volcano in ruins,

[1] On this Plate, as on that of Hawaii in the "American Journal of Science" (1888, vol. xxxvi.), most of the lettering of the original map is omitted, with necessarily minor details as to erosion and topography.

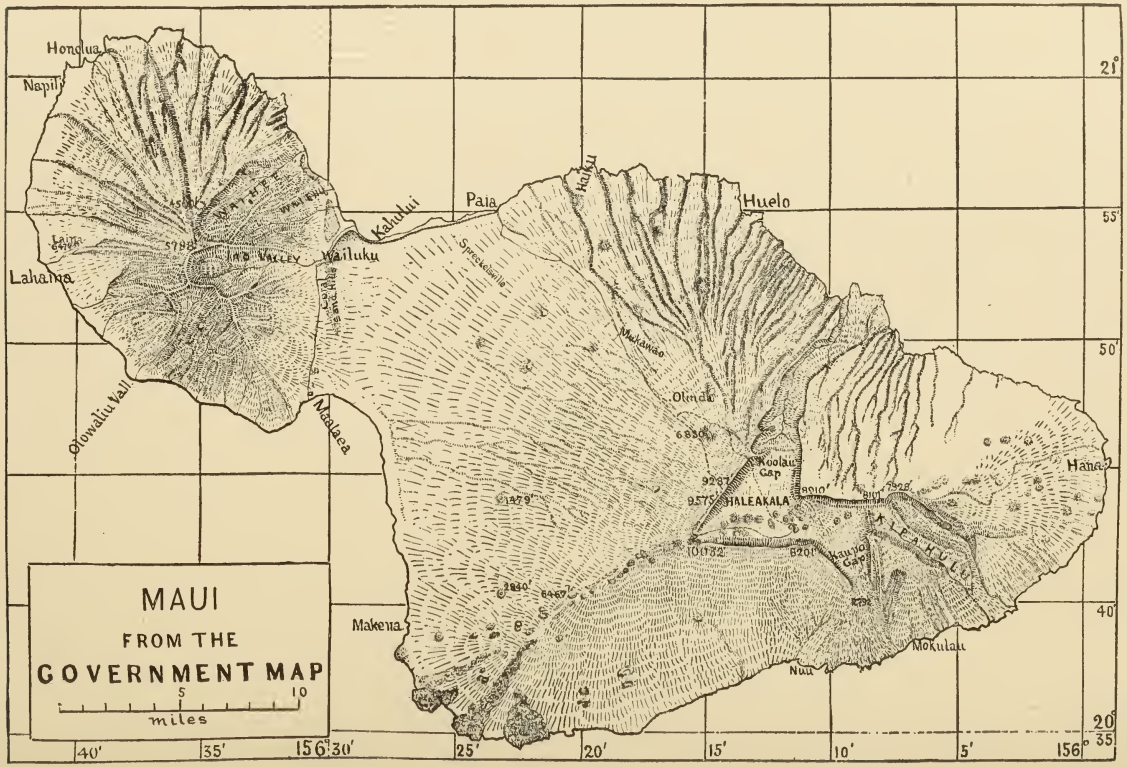
being profoundly cut up by valleys, and the original height reduced to 5,788 feet as the maximum.

(5) The low intermont area of Maui, made of the united bases of the two volcanoes, but covered for the most part by the lava-flows of Haleakala, whose fires continued in action long after the western volcano had been turned over dead to the dissecting elements; the width from north to south at the narrowest part, near the line reached by the lavas of Haleakala, about six miles, and the height at the survey station near its middle 156 feet.

In the account which has been given of the volcanoes, craters, and lava-flows, as well as the topography of Hawaii, it has been apparent that the maps of the Hawaiian Government Survey have been a very prominent basis for the conclusions presented. The Government map of Maui has still greater geological importance; for Professor Alexander, the Surveyor-General, has made it, by his accurate work and his appreciation of the importance of details, a contribution to science of the highest value and interest. What I have to say of the extent, depth, form, and discharge-ways of the great crater, of the heights and positions of cinder-cones, and of the erosion of the mountains, should be put mainly to the credit of the map, which was Professor Alexander's work, not only in superintendence and geodetic measurement, but largely also in the details of the survey.[1]

[1] The author, moreover, was personally indebted to Professor Alexander's kind providings, guidance, and instructions for the success of his trip in 1887 (August 4 to 6) up Haleakala and into the crater, where a night was spent, — an exceptionally brilliant night after a day of clear views from the slopes and the summit, — and also for his excursion up Wailuku valley on western Maui.

An excellent model of the island of Maui has been made by Prof. C. H. Hitchcock, who devoted much time to it during his recent visit to the Hawaiian Islands. The Government map was the chief source of data for the details. The vertical height is increased three times, and the craters and valleys are thus strongly brought out. All such exaggerated relief-maps, whether of a mountain or sea-basin, need a note of warning attached to prevent wrong conclusions as to slopes and heights; for the ratio of three to one changes a slope of ten degrees to one of twenty-seven and a half degrees. The light shading used on the map of Hawaii and here on that


MAUI
FROM THE
GOVERNMENT MAP
5
10
miles
Honolua
Napili
Lahaina
Kahului
Paia
Huelo
Hana
Wailuku
Iao Valley
5760'
Olowalu Vall
Maalaea
Spreckelsville
Haiku
Makawao
Olinda
6838'
Koolau Gap
9267'
9575'
HALEAKALA
10032'
8201'
Kaupo Gap
Makena
Nuu
Mokulau
21°
55'
50'
40'
20'
35'
156° 40'
35'
30'
25'
20'
15'
10'
5'
156°

1. East Maui.

The Mountain. — The crater of Haleakala has been many times described, but first with a detailed map in illustration by Captain Wilkes. Captain Wilkes states that he is indebted for the map to his artist, Mr. Joseph Drayton;[1] and considering that it was from an artist's survey, not that of a surveying party with instruments, it is a remarkable piece of work.[2]

The mountain is usually ascended from Paia, — a village on the north coast. The path, as the map shows, passes Olinda, and reaches the edge of the crater where the nearly vertical western wall bounding it is not less than twenty-five hundred feet in height. Thence it follows the summit southwestward to the southwest angle, passing Pendulum Peak[3] on the borders of the crater just before reaching it. Here are three cinder-cones, and the top of one is the culminating point of the mountain, 10,032 feet above tide. These summit cinder-cones stand at the head of a long line of similar cones extending southwestward down the mountain to the sea; and near the sea at the foot of the line are three or four comparatively recent lava-streams, — enough to illustrate the process of seashore extension by such sea-border outflows. At the summit, near the southwest angle of the crater and the base of one of the three cinder-cones, a cinder-made slope of rather easy grade begins its descent into the crater; it is the way down; on reaching the bottom the path continues

of Maui is intended to bring out the idea as nearly as may be of a mean slope of seven to ten degrees.

[1] Wilkes's Narrative, iv. 255.

[2] The Expedition owed much to Mr. Drayton, not only for his excellent labors as draughtsman in all departments at sea, but also, after his return, for his management of engravers, printers, etc., during the publication of the various Reports.

[3] The pendulum station of Mr. E. D. Preston, of the Coast Survey, in 1887. American Journal of Science, 1888, xxxvi. 305.

eastward to the usual place of encampment, four and a half miles from the top.

The two great Discharge-ways of the Crater. — Besides its lofty walls and great area, the most remarkable features of the crater are the two openings, a northern and a southern, a mile to a mile and a half wide, between precipitous walls of rock, — the walls of the northern two thousand feet and over, of the southern one to two thousand feet, — through which poured the lava of probably the last of the great eruptions. The Kaupo lava-stream — the southern — has much the smoother surface, as if more recent; but the broader Koolau stream descended the *windward* slope, and the consequent erosion may have made all the difference.

The Cinder-cones and Lavas at the Bottom of the Crater. — Another striking feature of the crater is the group of red and gray cinder-cones which stand over the bottom, sixteen in number, the highest nine hundred feet above its base, and all of them over four hundred feet, and yet looking small in the view of the great area from the summit. The sight to the northward when half-way to the bottom — comprising the northern discharge-way in the distance, the highest of the cinder-cones in the foreground, and beyond these and two other cones the broad stream of lava of the crater-floor as level apparently as a river, stretching away between precipices of more than two thousand feet, and then terminating in an even line at the limit of vision, as if there began the plunge to the sea — is wonderfully like the real river of lava on its downward way.

The cinder-cones of the bottom were evidently the last work of the fires. The ashy surface of the cones is without a trace of erosion, and thus bears no distinct marks of age. The slopes are mostly twenty-five to thirty degrees and less, and hence they may have had the pitch diminished somewhat by the winds and rains and earthshocks; there are no

channellings by descending waters. The material is scoria in coarse fragments and sands; and although in part reddish and purplish originally, the red color has generally been deepened by oxidation from exposure.

Besides the scoria, there are on some of the cones, especially those toward the borders of the pit, numerous large blocks of gray, compact, scarcely vesiculated rock. Some of the masses about a cone near the place of descent measured over a hundred cubic feet. The masses must have been torn off from the throat of the volcano's conduit, this being the only conceivable source. They indicate therefore the action of vast projectile force at these isolated centres when the cones were in progress, and its continuation even to the close of the ejections; and they also are probable evidence of very rapid work in the cone-making. A few of the other cones were grayish in color, as if from the abundance over their slopes of these projected grayish stones; but this supposition needs verification.

The cones stand, or appear to stand, on the rough, fresh-looking, scoriaceous lavas of the bottom, these lavas spreading away from beneath them. The opened fissures or vents which gave exit to the cinders first poured out the lavas; and then followed the cinder-ejections as the fires declined and the liquid lavas of the vent became somewhat stiffened. The cinder-material is proof of powerful projectile work; for the fragments of the exploding bubbles were thrown upward, as the heights of the cones prove, many hundreds of feet, — more than nine hundred to make the highest cone.

The fresh-looking lava spreading away in all directions from the base of the more western of these cones continues eastward throughout the crater, with little change of features, and with the same relation to the bases of the several cones, as if all pertained to one epoch of eruption, — the epoch of the last outbreak of Haleakala; the whole seems to have been the latest outflow of several subordinate vents.

after the crater had made its great discharge through the two gateways down the mountain.

This scoriaceous lava of the crater contains in many places much augite and chrysolite in largish grains or crystals, being both augitophyric and chrysophyric.

Lavas of the Walls and Summit. — The lava of the walls is in part scoriaceous; but on the south and southwest sides it was commonly a very compact, rather light gray variety of basalt, like that of the projected blocks about some of the cones. The layers of compact basalt had often one or more parallel planes of fine or coarse vesiculation, sometimes at intervals of one to three or four feet. At one locality on the ascent of the mountain the solid gray rock had been found to be a convenient stone for stone implements of various kinds, and a large manufacture was formerly carried on there; and yet near by the lavas that were so solid have occasional planes of coarse vesiculation, each one to three or more inches thick. Pendulum Peak, near the summit, just north of the southwest corner of the crater (the place of descent), consists largely of this compact light-gray basalt, with rarely any vesiculation visible without the aid of a pocket lens.

This compact basalt or doleryte is a common rock also over the lower slopes toward Paia. It appears thus to be to a large extent the material of the older lavas while also among the recent. At the summit on the west side, along the two miles passed over before reaching the place of descent, the compact variety of the basalt is rather the exception. There are large areas of the same scoriaceous lava that covers the bottom of the crater, and in some places it is equally augitophyric and chrysophyric, the augite in well-defined crystals. One of these areas is just north of Pendulum Peak; and a large region on the west border of the crater looks as if successive streams of lava had recently flowed one over another, piling up layer on layer, so that by this means the surface for a breadth of a mile or more westward from the

summit line had derived its unusual steepness of 15° to 16°. The lava-streams of the surface have the appearance of being overflows from the crater, — as if the great pit had been full to the brim before the outbreak, and had poured out from time to time small streams like those of a full lava-lake in Kilauea. But they more probably came from fissures cut through to the summit at the time of the last or some one of the later eruptions.

The fact that lavas of the summit are so very chrysolitic, even at a height of nearly ten thousand feet, has an important bearing on the question as to the effect of high specific gravity in determining the distribution of materials in liquid lavas.

Crystals of augite and large grains of chrysolite are common in the loose material at the base of the cinder-cones at the summit, near the place of descent, and colored glassy crystals of labradorite occur with them. These summit cones have the recent appearance and other features of those over the crater's bottom, and appear to be of the same series and time of origin; and the cinder-made slope into the crater on that side was probably made in part from the ejections of these summit cones.

The probable Nature of the last Eruption. — The great discharge-ways of Haleakala, one to one and a half miles wide, with the walled valleys confining them, look as if the results of enormous rents of the mountain, made when the mountain emptied itself by the wide channels. But they may have been in existence before, and have been simply used for the last of the outflows. They are, nevertheless, evidence of rents at some time, and of a vast amount of removal of material in some way, — by subsidence or otherwise. The height of the walls at the gaps — two thousand feet and over at the Koolau gap, and a thousand feet and over at the Kaupo — is a minimum measure of the amount of material removed. In my "Exploring Expedition Report" I suggest

that the mountain was fissured across along the lines of the two discharge-ways, and the eastern block shoved off a mile or two. But a subsidence of the masses that occupied them into caverns below, leaving the walls as fault planes, may be more probable. The abyss which received them in this case had been prepared during a long period of undermining through ejections. Still there is some reason to believe in the grander view of a subsidence of the whole eastern block, after the cross-fracturing. The island, as is seen on the map, is abruptly narrowed (instead of widened) at the spots where the Koolau and Kaupo streams reach the sea; and the part to the eastward is small, as if narrowed by such a subsidence. Moreover, the mean height of the eastern crater-wall is lower than that of the opposite or western by five hundred to a thousand feet. A subsidence of a thousand feet increasing in amount to the eastward would account for the narrowing and for the very short eastern radius of the eccentric volcano. The question merits investigation.

The evidence that the lavas were discharged in both directions at once at the last eruption consists in the nearly uniform appearance of the fresh lavas over the bottom of the crater from one end to the other, and their continuing into and apparently being the streams that descend the Kaupo and Koolau discharge-ways. Mr. J. M. Alexander has remarked that the crater is probably a double one, a combination of two great craters, as Mokuaweoweo at the summit of Mount Loa is compound in structure. This is no doubt historically true; but at the latest of the eruptions there was probably one action over the whole, the distinction for the time obliterated.

The period of the last summit eruption is unknown. Mr. Bailey, of Wailuku, Maui, has stated that, according to an island tradition, a *lateral* eruption of the mountain occurred about one hundred and fifty years since in the district of Honuaaula of the southern part of East Maui, at an

estimated elevation above the sea of about four hundred feet.

Activity of the Crater ending in Cinder-ejections. — The origin of the *crater* of Haleakala needs no explanation beyond that given in the remarks on page 149, on the origin of craters generally.

Haleakala is an example of a basaltic volcano which reached its end, through declining fires, in cinder-ejections; but it left its great crater open, and two thousand to twenty-five hundred feet deep, with the greater part of the bottom free from the cinders notwithstanding the amount discharged. The latest down-plunge or subsidence, by which the vast pit and perhaps also its discharge-ways were made, may therefore have filled full the empty subterranean chambers that former outflows had produced, and left the mountain solid instead of hollow. Mount Kea on Hawaii, 13,805 feet in height, also ended its work with cinder-eruptions; but the ejected material of lavas and cinders obliterated so far the old crater that no visitor of the region has yet found traces of its former limits. Whether Mount Kea is a hollow mountain or not remains to be ascertained.

After the above was written, the results of the pendulum investigations of Mr. E. D. Preston at the summit of Haleakala were made known in a paper published in November, 1888,[1] and they have afforded unexpected evidence on these doubtful points. They led him to the important conclusion that "the density of the mountain is at least equal to its surface density," and that therefore, unlike some results obtained on the continents, "it is a solid mountain," so that the interior must have been left filled by the subsidence of rock that made the great crater at the summit. He states also that "the zenith telescope observations at the foot of the mountain indicate the same fact."

[1] "On the Deflection of the Plumb-line and Variations in Gravity in the Hawaiian Islands," American Journal of Science, 1888, xxxvi. 305.

Mr. Preston states further that at Kohala, on the *north* coast of the island of Hawaii, the plumb-line deflections were half a minute *southward*, which, he adds, is well explained by the position to the southward of all the great mountains of Hawaii. He records also that at Hilo, on the *east* coast, the deflection was a fourth of a minute *to the northward*. Mr. Preston remarks that "there is no explanation" of this result at Hilo "unless we assume that the south side of Hawaii, where the volcanoes are active, is much less dense than the north side, where the fires have been slumbering for centuries." But to the north of Hilo is a long reach of ocean, the coast of Hawaii there trending northwest; the summit of Mount Kea, 13,805 feet high, is twenty-five miles distant and bears N. 75° W.; and that of Mount Loa, 13,675 feet high, is thirty-five miles distant and bears S. 63° W.; and the centre of gravity of the combined mass (the lowest level over five thousand feet) bears probably a little south of due west. It appears, hence, that we have here evidence that Kea is like Loa, *not* solid; that it is a hollow mountain, as inferred above from the absence of a summit crater; but Mr. Preston is probably right in his inference that Mount Loa is the more cavernous of the two. Additional plumb-line and pendulum observations are, however, much to be desired.

2. West Maui.

West Maui has lost the original slopes of its great cone and its crater through erosion. It has been supposed that remains of three great craters may be distinguished in the mountains: the largest at the head of Wailuku or Iao valley, on the north border of which rises the highest peak, Puu Kukui, 5,788 feet high; another in the less deep valley of Waihee, just north of this; and a third at the head of the Olowaiu valley, to the south.

The author has examined only the Wailuku valley, the

largest of the three, — so named from the village on the coast near its entrance. The valley is a deep cut into the mountains, remarkably grand in its precipitous walls with their thin-crested summits. It widens somewhat toward its head, and in this upper part an extensive plateau occupies the centre. The torrent of the valley is here divided between two tributaries, one running either side of the plateau. The height and rather bold sides of the plateau at the head of the valley, and its size and position, taken in connection with its location near the centre of the mountain range, appear to make it pretty certain that the plateau represents the floor, or rather what is left of the central area, of the great crater.

As to the former crater-condition of the other two valleys mentioned, nothing is known. The idea of their having been craters is based on the size, depth, and boldness of the walls and the amphitheatre-like head. But these features are common results of denudation in old volcanic islands, and therefore, in the question here considered, have alone little weight.

3. The Eccentric Form of the Maui Volcanoes.

The map of Maui illustrates a Hawaiian feature of volcanic mountains which may be common in other regions. The chief crater of the mountain is not at its centre. In Haleakala the ratio of the radii east and west of the crater is 2 : 3 ; and in West Maui, 8 : 11. The shorter radius is to the south-southeast of the crater in one and to the southeast in the other.

In Hawaii it is not easy to mark off the true base of Mount Loa. But we have the fact that in both the summit crater and Kilauea the form is oblong, and each has its intenser activity in the more southern portion, — the south-southwestern in one, and the southwestern in the other. The effect is not due to the winds, for the mountains consist almost solely of lava-streams.

4. Consolidated Drift-sand Ridge.

The positions of the high ridge of consolidated coral-sand of Wailuku are indicated on the map. Whether it is a proof of elevation or not is yet undecided. The sands are at the present time drifted by the trade-winds to the farther inland limit of these ridges and over their surfaces, — a fact which seems to show that present conditions are sufficient for their production.

B. ISLAND OF OAHU.

From the map of Oahu (Plate XIV.) it is apparent that in the first place the island consists of two eroded mountain regions, an eastern and a western, separated by a plain sloping gently downward to the opposite coasts and upward toward the eastern mountains. A more remarkable feature, secondly, is the long and high precipice of the eastern mountains, fronting northeastward, and thus facing the trade-winds. Besides these characteristics, there are lateral or subordinate volcanic cones on the sea-border, of which Diamond Head, Punchbowl, and the Koko Head craters on the eastern cape (Plate XIV., Figs. 1, 2, 3) are examples. Further the island is the only one of the group that has a nearly continuous coral-reef fringing the shores. It owes to this reef the harbor of Honolulu, the one good harbor of the group, and also the possibility of a much larger and better one at Pearl River, seven miles west of Honolulu; the cutting of a channel through the reef is all that is needed, as has long been recognized, to make these capacious inner waters available for shipping.[1] Another interesting feature (*e*) is the

[1] Honolulu, the capital of the Hawaiian Kingdom, was a collection of thatched huts in 1840, with exceptions only in a custom-house, an unfinished coral-rock church, and a few dwellings of civilized aspect. To-day it is city-like in its houses;

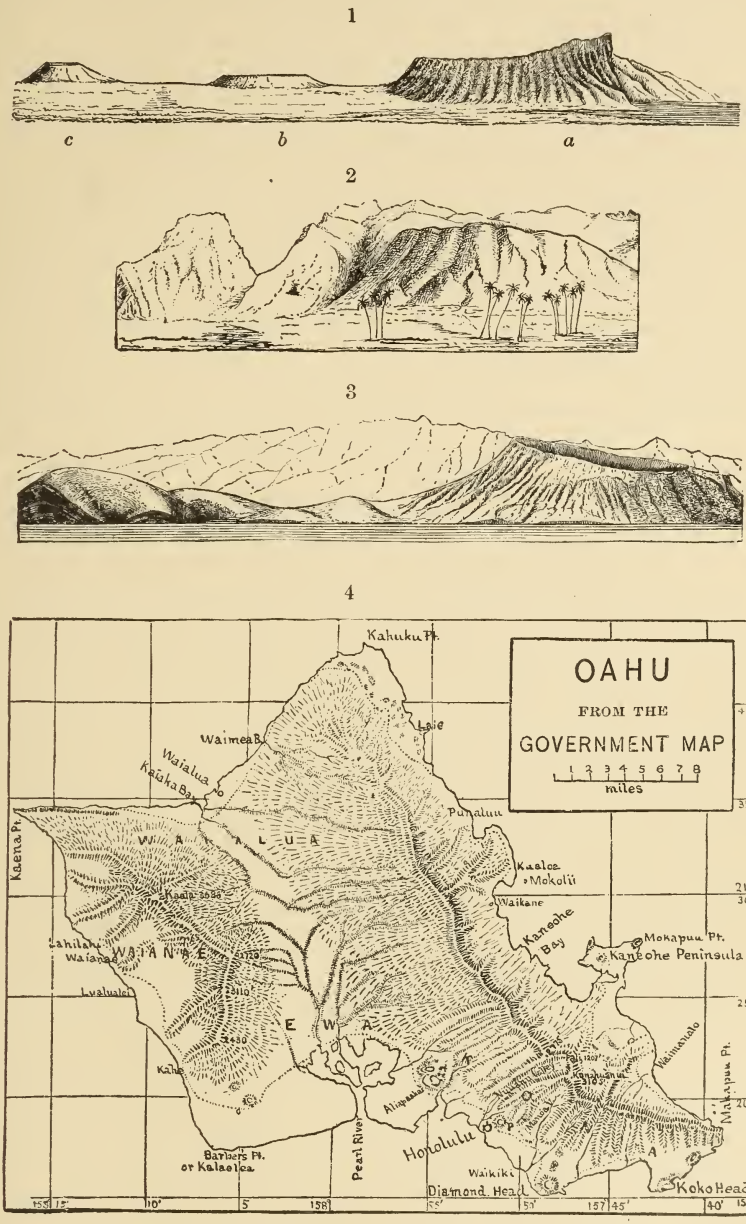


Fig. 1. The volcanic cones: *a*, Diamond Head, or Leahi; *b*, Kaimuki, or Telegraph Hill; *c*, Maaumae. 2. Punchbowl, or Puowaina; with Nuuanu valley to the left, and the peaks Konahuanui and Lunahili, right and left of the pali. 3. The Koko Head craters.

existence of an *elevated* coral-reef on the borders of the island, having its inner limits approximately indicated on the map by a dotted line.

The facts on which the following account of the island is based and the views deduced from them are for the most part contained in the author's "Expedition Geological Report." The accompanying map (Plate XIV.) differs little, excepting in improvement in outline and topography, from the colored geological map of the "Report," and the outline of the elevated coral-reef and its coral-rock and sand-bluffs are copied from it.[1] The views of the tufa-cones on the same plate are simply new drawings from some of the author's old sketches. Fuller particulars and some views not reproduced will be found in the "Report." Another excursion around a large part of the island, taken with President Merritt in 1887, refreshed old memories and added new facts.

1. Features, Structure, and Origin of Oahu.

General Features; Contrast with the Island of Maui. — Like Maui, Oahu is in origin a volcano-doublet, — that is, as regards rock-structure, it was the united work of two great volcanoes, a western and an eastern. But, unlike Maui, its two volcanic cones or domes have suffered so great loss that the position of either crater is wholly a matter of conjecture.

A large part of the loss Oahu has suffered is due to denuding agencies. East Maui, as the map on Plate XIII. illustrates, has lost in this way comparatively little of its original

its streets electrically lighted, its public squares, large hospital grounds, spacious government buildings, — among them a palace good enough for any potentate, — and its excellent hotel; and through the addition of groves and avenues of introduced palms and tropical trees (some of which are always in flower or fruit), it is fast becoming a place of ideal beauty. Honolulu is the centre of all the island activities, including inter-island navigation.

[1] The map of Oahu on Plate XIV. is reduced from the Hawaiian Government chart of 1881, made after a survey by Sereno E. Bishop, Assistant in the Topographical work.

evenness of surface, owing to the recency of its extinction. Its windward gorges are narrow, and only shallow gulches occur over the leeward surface. The ratio of its diameters at base, 1 : 1·3, is probably very near the original ratio. West Maui is profoundly gorged on all sides and most deeply so to windward, illustrating results of longer wear than East Maui has had. But something of the old slopes remain, and in the base we have still the ratio of its old diameters, 1 : 1·4, with the outline little indented. The double lesson is taught: (1) what denudation from descending waters does to a volcanic cone 5° to 10° in slope in the region of the trades; (2) what, on the contrary, the sea cannot do, no encroachments of note existing to attest to its power, notwithstanding the length of the era of denudation.

Oahu resembles Maui in having the western mountain-cone the most time-worn and the smaller in area, but here the likeness ends. Both of its mountains are deeply eroded. Further, only a section of the East Oahu cone now exists. The slopes of its southern, western, and northwestern sides remain; but the northeastern are cut off by a great precipice, twenty miles long, which is made for the most part of the edges of the lava-streams that slope southward and westward. The sharp-edged serrated ridge, making the summit of the precipice, is from one to three thousand feet in height, and at its northeastern base, from Kualoa eastward, there is in general only a narrow strip of land with low hills, the width but three or four miles except in the Kaneohe peninsula. The precipice continues beyond Kualoa northwestward, but not the low land at its base.

These features have occasioned peculiarities in the results of denudation on East Oahu. The *leeward*, or the southern, side of the island has long and deep valleys. Some of them head in broad amphitheatres under the crested mountain. But the broadest, the Nuuanu Valley, behind the city of Honolulu (see the map and left part of Fig. 2), has a gradual

ascent for six miles to the top of the precipice, or "pali," as it is ordinarily called, where it overlooks the northeastern sea-border plains and hills. The height of the "pali" is only 1,207 feet above the sea; but on either side are the highest peaks of the range, Konahuanui 3,105 feet in height, and Lanihuli, 2,775 feet. In the sketch (Fig. 2) the peak to the right of the valley is Konahuanui.

On the contrary, the *windward* side of the island, along the twenty-mile precipice, has buttresses and shallow alcoves, with a buttress here and there lengthened out into a ridge; and only farther northward, near Kualoa and beyond, are there the longer valleys or gorges and ridges, characteristic of deeply worn windward slopes. But along the whole range of the precipice and beyond, there is wonderful grandeur in the scenery. Bare rock might be expected in the lofty precipices and sharply cut or rounded alcoves, as in Colorado. But, instead, the steepest walls are green; and rocks are seen only here and there through the dark and dense foliage. The mountain back from the coast near Kualoa Point, twelve to fifteen hundred feet high, is one of the most remarkable of the architectural clusters of northeastern Oahu. It stands isolated, like a buttressed temple cut from the rocks; and one is led almost unconsciously to look for an entrance to the solemn grandeur of its interior.

Near Punaluu, a few miles farther to the northeast, a narrow gorge, called Kaliuwaa, has become a place of much resort on account of its narrow shaded recesses, its lofty walls, and the cascade that pours down the mountain trench at its head; but also for an almost cylindrical, smooth-sided shaft, thirty and forty feet in its diameters, which extends up vertically for at least three hundred feet. It is called by the natives "the canoe," the shape being nearly that of the body of a canoe standing on end. The lavas are light gray basalt, in layers as usual; but the surface is smooth, even over the junctions of the layers. Thoughts of falling water, of a local

lava-conduit, of chiselling natives, come up when before it; but the question, How? remains without a positive answer.

The many narrow gorges of this part of Oahu, richly draped in ferns and shrubbery, with streams begun in cascades and continued in dashing torrents, offer any number of tempting excursions. But the road down the "pali" on the way, while good enough for the active pedestrian, as in 1840, is for a horse and carriage only a breakneck way, impassable except as the horse is detached and led, and the carriage is held back with all available strength lest it take its own course down. The author had the best of it in 1887, for he took charge of the horse; but President Merritt had grave conflicts with the vehicle, though safe down at last.

Orographic Condition of East Oahu. — From the facts mentioned, it appears to be plain that the chief structural difference between East Oahu and East Maui is that the latter is a whole volcanic mountain, and the former a piece of one. By some means the Oahu mountain-cone or dome has lost a large piece from its mass, — all that once existed northeast of the twenty-mile precipice. The size of the lost piece it is not easy to determine. The lava-streams of the leeward slopes, which dip away from the precipice mostly at an angle of 3° to 5° (as seen in the intersecting valleys), must have come from some point or points beyond it to the northeastward.

Following the leeward slopes around westward and northward, we find all of them pointing upward toward the higher part of the mountains, as if the source were somewhere in that direction. But just where remains in doubt; and it is questioned whether there may not have been two or more great craters along the line.

No point or region has a more reasonable claim for consideration in this respect than the head of Nuuanu valley. In situation and width, and the features at its head, it is just what should be looked for in a great discharge-way. The

dip of the beds diminishes from 3° to 1° toward the top, and at the "pali" the beds were very nearly or quite horizontal. This is favorable to the conclusion that the crater was either at the head of the valley or near by it, just beyond the precipice. The low land below over the Kaneohe peninsula, and between this peninsula and the "pali," is a region of tufa-hills and other small cones, unlike any part elsewhere of the north or northeast coast. In addition, at the head of Nuuanu valley, very near the top of the "pali," there are the remains of a red cinder-cone. Besides this, on descending the steep "pali" by the path, there is to the east of the path a long broad slope, 35° to 40° in angle, consisting of reddish layers of volcanic cinders, scoria, earth, and stones, — indicating cinder-ejection from some point above, looking in 1887 very much as it did in 1840.

It is, therefore, most probable that the centre of volcanic activity for East Oahu was in the vicinity of the "pali," above the low region a little to the northeast of it. The cinder-cones above mentioned may have been results of the last efforts of the declining fires, like those of Haleakala and Mount Kea.

In 1840 the author was led to locate the central crater on the Kaneohe peninsula, the head of the "pali" seeming to be too near the southern foot of the mountain. But the fact that the volcanic mountains of East and West Maui are eccentric in ground-plan, and that the same feature quite certainly characterized this Oahu cone, makes the position near the "pali" the most probable. In Haleakala the centre of the crater is only six miles from the southern shore; and this distance in the Oahu crater, on the above supposition, would be about seven miles. The idea of an eccentric cone fourteen or fifteen miles in the transverse diameter through the crater is thus strongly favored. On further comparison with Haleakala, it is found that the part of the longer diameter of the mountains which lies northwest of the centre of

the crater is about nineteen miles in length on Maui, and on Oahu it would be nearly twenty-five miles. The small dip of 1° to 3° prevails widely about the mountains at Kualoa point and to the northward, as well as in the upper part of the Manoa valley, west of the Nuuanu; and from this it may be inferred that the East Oahu mountain was a dome, like Mount Loa, rather than a cone like Mount Kea. The existence of one or more craters west of the "pali" has been urged, and is possible; but no special facts that sustain this view have become known. The amphitheatre at the head of Manoa valley is referred to by Mr. Brigham as probably the site of a crater; but it may be only an amphitheatre of erosion.

Origin of the Long Precipice on Oahu. — The long precipice of East Oahu has been attributed to erosion. But there is no good evidence that such transverse walls are legitimate effects of erosion, either fluvial or marine. As illustrated on Maui (p. 286), the sea works with extreme slowness in battering lava-cliffs, and cannot work at all below the limit of forceful wave-action, — a level not twenty feet beneath the sea-level. Fluvial action makes long valleys in the long descending mountains, and has done grand work in alcoving the long precipice, and carving battlements and temples out of the rocky piles that were left, as is well exhibited in the Kualoa bluffs, while the sea has not even scraped away the small tufa-cones on its borders. It might be said that the cones of Kaneohe and the "pali" have been made since the era of erosion; but this disconnects their origin by a very long era from the period of activity in the crater.

Another view with regard to the origin of the precipice is presented by the author in his "Exploring Expedition Report;" namely, that it was made by a profound fracturing of the mountain dome across from southeast to northwest, and a drop-down of part of the outer or eastern section. The line of fracture was irregular, — the course rather of a series of

fractures; and subsidences of varying extent may have taken place along the line, becoming smaller to the northwest, where high ridges are left between the precipice and the coast. The amount of displacement was not less than the height of Konahuanui, 3,105 feet, and probably it much exceeded this.

Great catastrophic subsidences are not uncommon in volcanic regions. In the account of Maui and its crater the fact of a subsidence not less than twenty-five hundred feet, accompanying and following some one of its eruptions, appears to be placed beyond doubt. Hawaii has plain evidences about its crater of subsidences hundreds of feet in amount of displacement, if not thousands; and there are high precipices, like that at Kealakekua Bay, for which there appears to be no other probable origin.

The small western island of the Hawaiian group, Niihau, has a bold precipice as its eastern face, fifteen to eighteen hundred feet in height above the sea, and the lava-streams of the island pitch from the precipice to the westward, showing that the streams flowed from a point to the eastward, and that a large piece, perhaps the larger part, of an old volcano has disappeared. Kauai, north of Niihau, has its Napali cliff, a dozen miles long, along its southwest side, in a line with the Niihau cliff. Molokai, to the east of Oahu, was once, as its lava-streams prove, a doublet of volcanoes, like Maui; but it has been shaved down to a strip of land thirty-five miles long, and not a fifth of this in mean width. The eastern part has an alcoved precipice facing the north, which rises to a height of twenty-five hundred feet above the sea. It encloses a strip of land along the seashore; and on this spot, thus walled in, it has been found convenient to locate the Leper quarantine-ground of the islands. Lanai, a narrow island south of Molokai, about twenty miles long, has a bold front to the south and gradual slopes from it in other directions. Thus such precipices are rather the rule in the

Hawaiian group; and if seashore erosion is not the origin, —as many facts from the islands of the Pacific appear to show, — fractures and subsidence must be.

A great volcano is a disgorger of lava in vast floods, and so it makes its mountain; and it may also make empty cavities at the same time and as a consequence. As long as the ascensive force keeps the liquid lava-column of the active volcano fully up to the summit crater, the mountain may have only local cavities. But whenever a great discharge takes place, a coequal cavity may result; and if the discharge is from fissures at the base of the cone fifteen to eighteen thousand feet below the sea-level (not a greater depth than exists in the neighboring seas) an enormous cavity may be left, which only the renewed action of the ascensive force would fill. If the mountain *then* became extinct, with no return of the liquid, it would be a hollow mountain; and the greatest of subsidences which the Hawaiian facts seem to indicate, are small compared with the possible consequences of such a condition.

2. Tufa and other Lateral Cones of East Oahu.

Several of the tufa-cones of Oahu are represented, as already stated, on Plate XIV.

Punchbowl (Fig. 2) stands on the northern border of Honolulu (at P on the map).[1] Its highest point is 498 feet above tide-level. The tufa of the beds constituting it, though rather feebly consolidated, is quarried on the west side of the cone, and specimens may there be conveniently obtained. It is a yellow to brown, in part resin-lustered, palagonite-like rock, bearing evidence, in its constitution and in the dip of the beds, that mud-making warm waters were concerned in the deposition; and the brown, in place of red, color is probable

[1] The sketch was taken in 1840 from the deck of the ship "Peacock" as she lay in the harbor. The native huts at its foot are omitted.

evidence that the temperature of the water was below 200° F. Punchbowl — Puowaina of the natives — has recently been converted into a Park.

Diamond Hill (Fig. 1) makes the prominent cape east of the city; its bold southern brow has a height of 761 feet above the sea at its base. It is, like Punchbowl, a fine example of the typical tufa-cone in its broad and shallow saucer-shaped crater, with the stratification parallel to the bottom of the saucer and to the original outer slope. These slopes have become deeply trenched, as the view shows, by descending waters; and since 1840 the southern brow has lost something of its boldness. Two other cones stand in a line to the north of it, — the first a place of lava outflow. The three vents appear to be situated on a single line of fracture.

The Koko Head tufa-cones are situated at the east extremity of the island. The view (Fig. 3) was taken from the eastward at sea. The larger or more northern of the two cones is much denuded inside and out. The other low cone, situated on the Point, is worn to its centre by the sea, and has thereby been made to exhibit to the passing vessel (as it goes from or toward Honolulu) the dip of its tufa-beds inward and outward, and thereby the true structure of such a cone.

Artesian borings on Oahu afford some facts bearing on the history of Diamond Head and Punchbowl. The borings were made by Mr. J. A. McCandless of Honolulu, and records of a number of them have been received from him through Prof. W. D. Alexander.

The following section is from James Campbell's well, at the west foot of Diamond Head, not far from the sea-level.

	Thickness.	Depth.
Gravel and beach sand	50 feet	. .
Tufa like that of Diamond Head	270	320 feet
Hard coral rock, like marble	505	825
Dark brown clay	75	900
Washed gravel	25	925

	Thickness.	Depth.
Deep red clay	95 feet	1,020 feet
Soft white coral	28	1,048
Soapstone-like rock	20	1,068
Brown clay and broken coral	110	1,178
Hard blue lava	45	1,223
Black and red clay	28	1,251
Brown lava	249	1,500

The well went down 1,178 feet before reaching the solid lava of the bottom. In its upper part it passed through 270 feet of tufa, indicating that the tufa-cone extended below the sea-level to this depth, and therefore had a total height of over 1,000 feet. Below the tufa, between the 320-foot and 825-foot levels, there are 505 feet of *hard coral rock;* and then, on the 1,048-foot level, a 28-foot layer of *soft white coral*, and at a greater depth brown clay and broken coral. As the well is close by the west foot of the Head and passes through so much of its tufa, it is quite certain that the 505-foot stratum of limestone was made before the tufa-eruption, and that the beds underneath it mark earlier conditions over the site.

As regards a supply of fresh water, the well was a failure, — an exception to the usual experience. The water came up salt, and a much stronger brine than sea-water. It was under some pressure, as it stood a foot above the level of surface wells near by.

Other borings have been made in Waikiki, — the sea-border district just west of Diamond Head. The section afforded by the deepest of the Waikiki wells is here inserted for comparison. It is that of the King's well, No. 2, — about half a mile west of Diamond Hill and 350 yards from the seashore.

	Thickness.	Depth.
Sand and coral	38 feet	. .
White coral	22	60 feet
Yellow sand	43	103
Hard lava	47	150
White coral	110	260

	Thickness.	Depth.
Blue clay	25 feet	285 feet
Tough clay and coral	65	350
Blue clay	30	380
Hard coral	40	420
Soft coral	30	450
Tough clay	5	455
White coral	40	495
Tough clay	30	525
White coral	100	625
Tough clay	5	630
Coral and clay	70	700
Tough clay	28	728
Black sand	2	730
Lava	120	850

In this well the upper 320 feet probably correspond approximately to the upper tufa-made portion of the preceding. It is remarkable that tufa is wholly absent, although the distance from the active vent was so small; but this is accounted for by the direction of the trade-winds, which would have carried the ejected material seaward, — the direction in which the hill is elongated. Moreover, the tufa-cone, although 1,000 feet high, may have been thrown up in a single year or less. Instead of tufa for the upper part, there are underneath 38 feet of sand and coral, 22 feet of white coral; 110 feet more of a coral layer above the 260-foot level, and 65 feet of "tough clay and coral" next above the 350-foot level. Further, beginning with the 380-foot level, a coral layer continues to the 700-foot level, or for 320 feet, with the exception of forty feet of clay divided between three layers; and this 320-foot layer appears to correspond to the 505-foot layer between 320 and 825 feet in the other section. The solid lava-stream of the bottom of the well was reached at 730 feet. The amount of water obtained proved that the lava-stream was one of those from the mountain. It is overlaid by two feet of volcanic sand and 28 of tough clay, the sand serving to contain the water and the clay to confine it, conditions suited to make the well a success.

In these sections the intercalated beds of so-called "clay" vary widely in position and thickness, and appear to be, in general, local deposits of decomposed rock from mountain streams, or tufa-deposits from one source or another. In another boring in Waikiki, a bottom of solid lava was reached at 375 feet; and in a third, Goo Kim's well, at 475 feet. The former had an intercalated lava-stream at a depth of 106 feet, and the other at 150 feet. In Goo Kim's well, which was nearly a mile from the seashore, there were 26 feet of coral-rock above the 150-foot level, and 194 feet of coral above the 430-foot level, but with two intercalations of a 20-foot layer of "clay" in the stratum. The facts as to the varying levels of the "clay" beds and the intercalation of lava-streams show what accidents the living species of the sea and its reefs were exposed to. They make the existence of a *continuous* 505-foot stratum of coral limestone underneath the tufa of Diamond Head the more remarkable.

The artesian wells made within the limits of the city of Honolulu might be expected to throw light on the history of Punchbowl.

1. A well in "Thomas Square," just south of Punchbowl, afforded the following section: —

	Thickness.	Depth.
Soil 6 feet, with 6 of black sand and "clay" 4	16 feet	
White coral (at top, the elevated reef)	200	216 feet
Brown clay	44	260
Coral	10	270
Brown clay	60	330
White coral	50	380
Brown clay	80	460
Bed rock or lava, penetrated	49	509

2. In "Mr. Ward's well," below Thomas Square, on King Street, there were at the top 15 feet of loam and sand, then 180 feet of "hard coral rock," carrying the depth to 195 feet; again 24 feet of coral and shells above the 219-foot level; and then, underneath 109 feet of "yellow clay,"

which may be Punchbowl tufa, 23 feet of coral above the 393-foot level, and 107 feet of white and yellow sand below it; with the bottom lava at 508 feet covered by four feet of quicksand. An abundant flow of water was obtained.

3. South of the last, in the "Kewalo well," begun near the sea-level, beneath six feet of black volcanic sand, there were 50 feet of coral over a 40-foot layer of hard lava; then 190 feet of coral, divided in two by an intercalated 30-foot layer of "clay," over the 350-foot level; with the bottom lava-bed at 620 feet.

4. Section from a well in the Palace yard: —

	Thickness.	Depth.
Soil 4 feet, black sand 4	8 feet	. .
Coral	64	72 feet
Hard lava	6	78
White coral	60	138
Clay	240	378
Coral	75	452
Clay and gravel	254	707
Lava or bed rock, penetrated	55	762

Of the above sections, 1, 2, and 3 have a thick bed of clay on the 260-foot to 280-foot level; 1, 2, and 4 on the 330-foot, 370-foot, and 378-foot levels; 1 and 2 and 3 on 460-foot, 500-foot, and 535-foot levels; and No. 4, a layer 254 feet thick on the 707-foot level, or the bottom rock. It is possible that one or more of these of "clay" may be decomposed tufa of Punchbowl origin. But to refer all to this source would make the period of eruption of very improbable length. The "black sand" below the soil in Honolulu is naturally referred to this source. But more investigation is required for a decision. There is no evidence that Diamond Head and Punchbowl were of simultaneous origin.

Salt Lake Region. — The salt lake of Oahu occupies a depression surrounded by a low ridge, and is situated about three fourths of a mile from the sea, and seven to eight miles west of Honolulu. It is not at first apparent that its site

was once a region of hot water and tufa eruptions; yet from the character of the tufa and the direction of its dip such was the case. There were evidently several vents of considerable lateral extent, but of small force, and they resulted in producing a plain a mile and a half in its longest or east and west diameter, bounded by a tufa-made ridge 150 to 375 feet in height.

Ascending the north side, or that away from the sea, we look down on still another flat plain surrounded by a ridge. In its western corner there is a deep bowl-like crater and a small fresh-water lake called *Aliamanu,* with a circular wall of stratified tufa 486 feet above tide-level on its north side. In structure and composition, the walls resemble those of the other tufa-cones.

Fragments of chrysolite are sometimes found in the tufa of this region half an inch in diameter, resembling the large crystals observed occasionally in some of the compact gray basalts of the mountains. I observed no lavas which had flowed from any of these vents.

There is still a third basin, situated to the west of the first, near the borders of the Pearl River lagoons. It is a flat plain, nearly circular, surrounded by a low ridge, and has an area about half the size of the last.

These three basins occupy together a region about twelve square miles in extent. The more northerly is about fifty feet above the lake; and the lake was found by the Expedition to be near the level of the sea at half tide.

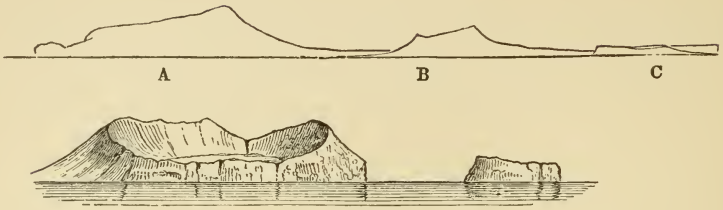
The *salt lake*, called by the natives *Aliapakai*, was, in October, 1840, nearly a mile wide in its longer diameter, and half a mile in the transverse, and occupied about half the area of the basin in which it lies. It had been supposed to be fifty fathoms deep, but the long line prepared for sounding it descended only sixteen inches. This was in November, 1840, at which time it was surveyed by officers from the Wilkes Exploring Expedition. In the November of the year

following, when examined a second time by the author, there were but *six inches* of water; and instead of finding salt only about the stones of the shores or on some planted twigs, the whole bottom was covered with a crust of salt averaging three inches thick, and hard enough to support a team of horses. The surface of the crust consisted of brilliant cubes of salt, mostly a third of an inch in their dimensions. In some places the salt stood up in knobs as large as the fist, consisting of clustered crystals; and there were columnar or finger-shaped aggregations, made up of a series of these large cubical crystals, which had formed horizontally from the knobs, or parallel with the surface of the water, instead of erect, — a position evidently due to currents in the water produced by the winds, as they pointed to leeward. They were quite pure, and had no nucleus, excepting a few granules of dirt along the centre. Aliapakai is still a salt-water lake, at mean-tide level, and is about 4,000 and 3,000 feet in its diameters. Aliamanu is fifty feet above tide-level, and 2,000 by 1,300 feet in its diameters.[1]

Kaneohe Point. — The east point of Kaneohe Bay is a small peninsula, eight or nine square miles in extent. Excepting the volcanic hills, the surface is nearly flat, and is formed of coral limestone, elevated a few feet above high-water level. There are four of these hills, of which three have remains of craters, more or less distinct. The largest of the craters occupies the outer extremity of the peninsula. Its walls are broken away on the western side, exposing to view the bowl-shaped cavity within. It is like Diamond Hill, except that the inner walls are more furrowed. The sea washes its foot, and the broken condition is owing to the action of its waters. The following sketches show the outline of the point in a view from the northwest. and the general appearance of the largest crater (A) and

[1] These measurements and the heights above are taken from a tracing of an unpublished map recently received from Professor Alexander.

an island (N) off the point to the northward as seen from the northeast : —



Crater A and the Island N.

The crater B, next in size to A, stands back about three fourths of a mile from the sea, near the western side of the peninsula. In a distant view this crater has a high conical form, and is obliquely truncated at top. It is mostly a lava-cone; and black rocks form a large portion of its northern walls, besides half filling the shallow crater. The outer surface is mostly loose soil. The lava of the eruption flowed off to the northward toward the sea, but is concealed to a great extent by the coral sand-hills that have accumulated on this side of the peninsula.

The crater C is also a lava-crater. It is broken down nearly to the level of the sea, excepting the eastern and western sides, which stand like two rocky hills sixty or eighty feet high. The lava is like that just described, and much of it is broken into large blocks, which lie in confusion together.

There is also a small rounded elevation half a mile to the southeast, which consists of the same basaltic rocks, although there is no distinct crater at the present time. They are not connected with those of the vents just described, and must have been ejected at the spot where they now lie. This is, therefore, a fourth vent.

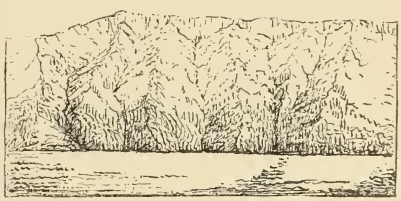
The small island of rock (N) standing off Kaneohe Point must be a remnant of a fifth cone.

The tufa-craters described were probably formed previous

to the elevation of the island of twenty-five to fifty feet, referred to beyond; and if so, the vents at the time of the eruption were not above the sea-level. This condition is that most favorable for the making of a tufa-cone.

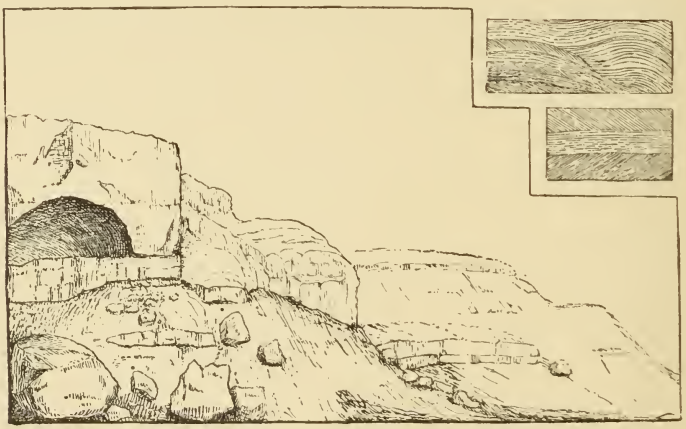
West Oahu. — The mountains of West Oahu cover at the present time a much smaller area than those of East Oahu. Their original dimensions we have no data for estimating. The highest peak, Kaala, in the northeast part of the group of summits, has a height, according to the Government survey, of 3,586 feet, — which is 681 feet greater than that of Konahuinui; and besides this there are in the southeastern part peaks of 3,105 and 3,110 feet. These elevations and the deep and open valleys divided off by sharp ridges are sufficient evidence that the mountain-range is but a small remnant of the once great volcanic mountain, — probably a loftier mountain than that of East Oahu. Denudation has had a far longer time for its dissecting work, and has done much to diminish the area it covers. Whether great loss has resulted also from subsidence is not ascertained.

The fact that the volcano of East Oahu was in full action long after the extinction of the western cone is shown (as the author first observed in 1840 and again in 1887) by the encroachment of the eastern lava-streams over its base, and the burial in part of the valleys. The accompanying sketch is a view, looking westward from the plain that was made by the encroaching lavas; it shows how the lavas dammed up the already made valleys of West Oahu, and forced the drainage waters to take a north or south direction, nearly parallel with the base of the mountain, in order to reach the sea. The courses of these streams are given on the map. The depth of burial by the East-Oahu lavas was probably some hundreds of feet.



3. Evidence of Recent Change of Level.

1. *Elevation.* — Evidence of recent upward change of level is afforded by the elevated coral-reef along the sea-border. The dotted line on the map (Plate XIV.) has already been pointed to as approximately the inner limit of the raised reef; the small dotted areas about Kahuku Point, the prominent north cape of the island, and in Laie, the district next southeastward, besides others west of Waimanalo, are the positions of hills or bluffs made of the reef-rock and consolidated drift-sands. The rock is in some parts a beautiful white fine-grained building-stone; but generally it has sudden transitions in texture and firmness, and much of it is a consolidated mass of broken corals, or else of standing corals made compact or nearly so with coral-sand. Along southern or southwestern Oahu the height of the reef is fifteen to thirty feet; and I estimated the amount of elevation indicated by it in 1840 at twenty-five or thirty feet.

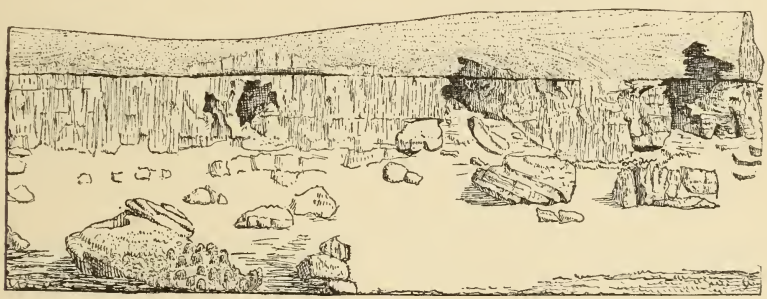


Kahuku Bluffs of Coral-rock and Drift-sands, with two Sections of the Drift-sand Rock.

At the Kahuku bluffs, which I visited anew in 1887, the solid coral reef-rock extends up in some places to a

height by estimate of fifty to sixty feet above tide-level; and this is surmounted by drift-sand rock, made of beach coral-sands that were drifted into hills on the coast when the reef-rock was submerged, adding twenty feet or more to the height. There are large caverns in the bluffs, which are mostly within the upper layer of the coral-reef rock and have the drift-sand rock as the roof. In the preceding sketch a faint horizontal line may be seen passing by the top of the cavern; it separates the beds of different origin. The coral reef-rock consists mostly of cemented masses and branches of corals of the kinds common in the modern reef, and also has often the corals in positions of growth. But the wind-drift beds consist of sand, and show the abruptly varying pitch in the layers common in wind-made drifts, as represented in the two sections to the right above.

Another and more extended view of the bluffs is here added from a photograph by Dr. J. S. Pratt, of New York, taken on



KAHUKU BLUFFS, CALLED KAHIPA (from a photograph).

the 5th of September, 1889.[1] It exhibits finely the abrupt transition from the coral-reef rock to the drift-sand rock by the horizontal line of crevices which erosion has made, and also brings out distinctly the variations of pitch in the layers of the latter.

The change of level along northern Oahu, according to

[1] The author is indebted for the photograph to A. F. Judd, Chief-Justice of Honolulu.

the facts from Kahuku, appears to have been at least fifty feet, or twenty feet greater than the facts on the southern side indicate. Even with an accurate measurement of the height of the reef-rock the amount of elevation would remain doubtful, because the coral-reefs off the island are at present rarely up to low-tide level; and this may or may not have been the fact before the change of level took place.

The surface of the elevated reef of Oahu is exceedingly uneven from unequal construction and erosion, and its interior has in some places large and winding caverns, so that an overlying formation, were there one, would afford an example of *unconformability by denudation*. It is obvious that with greater elevation the unevenness would be as much greater, — large enough to get the credit, perhaps, of representing an interval of many thousands of years, although results of the "modern" period in geology. Denudation works rapidly among limestones, and especially so when the limestones have just left the water, with the usual irregularities of upper surface and texture.

2. *Subsidence.* — A former subsidence of the island is apparently indicated by the coral-rock, through the depth to which it has been found to extend in Artesian borings. In these borings, described above, a depth of seven to eight hundred feet was found for the coral-rock, and more than one thousand for broken corals; and over seven hundred is reported by Mr. McCandless from a well in the Eua district, about five miles west of Honolulu. The facts lead to the inference that the subsidence amounted to at least eight hundred feet, and that it corresponds to the coral-reef subsidence which Darwin's theory requires. Mr. McCandless informed me that fragments of corals like those of the modern reefs were brought up from the various levels.

This evidence of subsidence to the amount stated is not, however, complete. Doubt remains because the corals brought up in fragments have not been examined by any one compe-

tent to decide on their actual identity with existing species; I could not find that any of them had been preserved. In a series of specimens of the beds passed through in an artesian boring in Honolulu, on the property of Mr. J. B. Atherton, for which I am indebted to President Merritt, coral or shell sand occurs more or less freely in all the samples, and some consist wholly of such sand, or of sand and larger fragments; but the fragments were in general from the reef-rock, or if from corals, not of sufficient size for the identification of species. The well was carried to a depth of 655 feet, and beds of coral and shell sand were found at the following depths: between 12 and 65 feet, 70 and 190 feet, 200 and 230 feet, 275 and 280 feet, 290 and 320 feet, 355 and 400 feet, 455 and 480 feet, and 505 and 515 feet. The facts are not sufficient to answer the question as to the species that contributed material to the calcareous beds.

We may hope that the study on the island of the specimens brought up in future artesian borings will remove the doubt that remains.

III. ISLANDS OF KAUAI AND NIHOA.

A. KAUAI.[1]

Kauai is nearly circular in form, and has an average diameter of twenty-nine statute miles. The land rises very gradually from the coast, except on the western side, where there is a precipice fronting the sea of one to two thousand feet. Elsewhere there are usually cliffs of two or three hundred feet, above which commences a gently sloping shore-plain, two to five miles wide. This cliff occasionally retreats inward, leaving a sea-coast plain surrounded by an amphi-

[1] This description of Kauai consists of extracts from the author's "Exploring Expedition Report" on the island, which was based on explorations for the larger part of a week in 1840.

theatre of steep hillsides. The surface of the interior is broken into ridges and valleys, many of great extent. The loftier summits tower up with steep, unbroken sides three or four thousand feet above the other heights around them, and some of the gorges are one to two thousand feet deep. The altitude of Waialeale, the highest peak, is estimated at eight thousand feet. Toward the west side of the island there is a mountain plain about four thousand feet above the sea.

The valleys of Kauai are as much more extensive than those of other islands of the group, as its peaks are more irregular, abrupt, and broken. Hanalei valley, which opens on the northern coast, is a wide plain for many miles, though becoming a narrow gorge above; it separates a ridge on the east from the mass of mountains on the west. Hanapepe valley opens on the opposite or southern shore, and is one of the most extensive in the island and also the one most to be enjoyed for its beauty. Its waters, like those of Hanalei, rise in part from the peak Waialeale. At the "Falls," four miles up the valley, "we were in an amphitheatre of surpassing grandeur, to which the long defile with its fluted or Gothic walls, decorated with leaves and flowers and a succession of cascades, made a fit entrance-way. On the left there stood, apart from the walls, an inclined columnar peak or leaning tower, overhanging the valley. From a gorge on the right, where the basaltic rocks stood out either side in curved ascending columns as if about to meet above in a Gothic arch, a stream leaped the precipice and fell in dripping foam to the depths below, where, gathering again its strength, it went on its shaded way down the gorge." The Wailua, the chief river of eastern Kauai, also has its noted waterfall; but it is situated within the shore plain, two and a half miles from the sea. The stream, about thirty yards wide, divides and descends a precipice of one hundred and sixty feet. For the last two miles of its course the width is about fifty yards, and the depth sufficient for canoes; but, owing to

the sand-bar at its mouth, its fifty yards at the end become three or four. Nearly all the smaller streams are closed in a similar way by bars made of coral-sands, and so completely that they may generally be crossed at mouth on dry land, the water escaping through the sands.

Among the lofty summits of the interior there is no well-defined crater. The ridges, as they reach toward the sea, are very distinctly seen to decline gradually into the shore plain, this plain being, in fact, but the base or foot of the mountains, continuing the slope of the ridges to the sea. Moreover, the plain and the ridges show not merely a continuity of surface, but also of internal structure. The river channels which intersect it, like those of the dividing plain of Oahu, are often three hundred feet deep, and have a uniform stratification, which extends, without changing essentially its inclination or general character, far toward the centre of the island.

The layers are remarkably regular, and dip with the slope of the plain at an angle of one to five degrees. They are so nearly horizontal that the inclination is often hardly apparent. The dip is away from the interior toward the shores, the layers rising gradually toward the interior from the southern, eastern, and northern sides. The layers differ much in thickness, and enlarge toward the interior; within five miles of the sea they vary from ten to one hundred feet in thickness: twenty to twenty-five feet is the mean.

The rock is the usual light gray basalt found on Oahu and to the eastward. It varies from scoriaceous, recent-looking lava to the most compact. Chrysolite is usually present, and in the Hanapepe valley masses that had come from the mountains contained crystals an inch or more in their several dimensions. A tendency to a columnar structure is common in the layers, and in some regions, as in the valley just mentioned, the columns are well defined and a marked feature in the scenery.

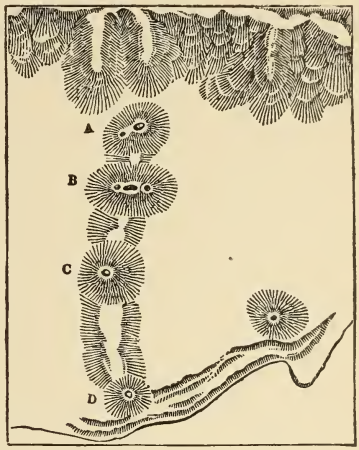
Curved columns often occur in places where at first it

seems difficult to account for them by reference to the position of the cooling surfaces. The *middle* or *interior* of a layer, which in other parts is vertically columnar, presents at times singular examples of contorted columns; the straight columns curve to the right or left for a short distance, and then gradually resume their original direction. The explanation may be found in the fact that over streams of cooling lava steam-holes remain for many months, and sometimes for a year or more after the eruption has ceased, emitting hot air and vapors; and under such circumstances the cooling of the interior must take place very unequally; curvatures of various forms might thus be produced, and still derive their peculiarities from the position of the cooling surfaces, or, what is equivalent, the direction in which the heat was drawn off.

Besides the mountains and hills which along with the shore plain constitute the great mass of the island, there are some ridges near the eastern shores which appear to be distinct from the rest, since they lie between the border plain and the sea. One of these is the Hoary Head Ridge, which stands along the southeast corner of the island and passes inward toward Koloa. It has an abrupt front toward the interior, and an uneven serrated outline. Wailua River cuts through one of the ridges about half a mile from the sea; and near by parallel layers of lava were distinct to the summit of each of the rugged peaks, dipping eight to ten degrees northeastward or nearly toward the sea. A similar dip occurs in the summits a few miles south of Wailua, near Nawiliwili. Eight or nine miles north of Wailua, back of Anahola, on the northeast shore of the island, there is a high border ridge with needle summits in which the usual stratification is apparent. One of the curiosities of the place is a hole through one of the summit needles near its base.

Kauai has also its lateral craters near the sea in the vicinity of Koloa, much resembling those of Oahu. An area

of eight or ten square miles, containing several cones, is represented in the accompanying map. Black lavas, as bare as many of the lava-fields of Mount Loa, form the surface over a large part of the area, and the lava-streams often have a ropy exterior and are bulged up into domes and ridges like modern lava-streams. One of the domes not far from Koloa contained within an open space or cavern, ten feet high, twenty broad, and fifty long, and the bulged layer which made the cover was about five feet thick; it was evidently a vapormade bulge. The roof was very rough, but not stalactitic. The waves of the ocean, driving over the black rocks into dark recesses, and rising in copious jets or dashing into foam, afford majestic sights wherever seen about these volcanic islands; and some of the spout-holes of Koloa are unusually grand.

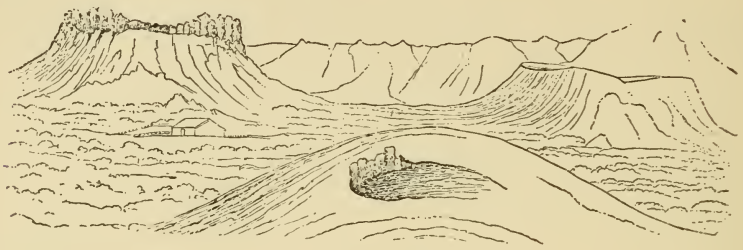


KOLOA VOLCANIC DISTRICT.

The Koloa lava is the common black or brownish black, somewhat cellular basalt of such regions; and it is sometimes columnar. Along the banks of a stream there are well-defined prisms, about eighteen inches in diameter. The horizontal joints are flat, not concave. The number of volcanic hills is five; and among them one contains two craters, and another three craters, as shown in the preceding map. With one exception, they are low, with a rounded contour and barren earthy sides, looking as if made of dark-colored brickdust.

The one exception, called the Old Crater, is represented to the left in the accompanying sketch. It stands about one hundred and fifty feet above the plain. Its steep and ragged summit consists of dark brown lava and scoria. The bare

sides are smooth till near the summit, where the lava breaks out in columns, so rude and jagged as scarcely to be columns, yet appearing columnar from below. It forms a narrow wall, or crest, broken by numerous rents, and is mostly



The "Old Crater" and Others of Koloa.

wanting on the east-southeast and west-northwest sides. The crater is about one hundred and fifty yards wide at top, and has a depth of thirty or forty yards. The surface within is smooth, and consists of red earth, like the lower slopes of the exterior.

The lava of the crest owes its roughness, in part, to a thin laminated structure and numerous vertical fractures. The laminæ are from half an inch to two inches thick; and although not easily separated, they stand out prominently over the worn or decomposed surface. The rock has been rendered very irregular from disintegration, and at top the columns are sometimes unevenly tapering. Besides these sources of its rough features, the walls within are covered with lava in twisted shapes, forming patches plastered on the surface or hanging in stalactites. The rock of the crest is very cellular, and much of it is scoriaceous.

To the eastward of the Old Crater, about three fourths of a mile, there is the small hill, with evenly rounded top, represented in the foreground of the preceding sketch. It has a shallow cavity, about one hundred feet in diameter, broken down on one side, with walls of semi-columnar lava on the other. The lava is lamellar in structure, like that of the

Old Crater, and the surface is covered with ropy and twisted slag-like scoria.

The lavas of the Koloa district probably issued from some or all of these craters, and from fissures in the plain. All the hills, with one exception, lie nearly in the same line; and hence a large fissure was probably opened in the direction of this line, from which the eruptions took place, certain points along the fissure becoming vents for continued eruption and giving origin to the cones, — the usual mode of action on Hawaii and in other volcanic regions. In the Old Crater the lavas appear to have boiled up to the top, and thus formed the crest, as a ridge is formed around a lake in Kilauea, and then subsided again, leaving the sides covered with pendent masses of scoria.

The red soil of the Koloa district resembles that in other parts of the island. The effect of the growth of vegetation upon it, in bringing the iron into new combinations with organic acids, is seen about Koloa, where there is a foot or so of dark loam. The cavernous surface of these lavas appears to soak up whatever waters fall, and the region is mostly barren except in the immediate vicinity of Koloa, where there is a fine stream and some marshy soil.

The island of Kauai is thus like the other Hawaiian islands, in (1) the generally basaltic character of its lavas; (2) the dependence of its slopes, and of the dip of the lava-streams in the central mountains and of the border plain, on the pericentric discharges of a great central vent, once existing in the region to which the dips around point; (3) the gentle angle of the lava-flows from the vent, ordinarily one to five degrees, and often hardly distinguishable from horizontality; and also (4) in its recent-looking lateral cones. Moreover, the valleys and peaks indicate that its fires long ago ceased, — as long ago as those of eastern Oahu, if not before.

The elevated plain in the western part of the island, about four thousand feet high, needs special investigation as to the

dip of the layers; and so also the lofty precipice on the side fronting to the northwestward. There may be indications, as has been supposed, of a second great cone, and of the loss of a part of its mass by a profound subsidence. The fact that this precipice of Kauai has the same direction as, and is nearly coincident in line with, that of eastern Niihau, the island to the southwest, and that Niihau has beyond question lost the larger part of the original cone or dome by engulfment, are evidence that the subsidence appealed to is not an improbability.

With regard to the origin of the eastern shore-ridge, there remains much doubt. It may be the result of a faulting and uplifting of the strata; yet this is not probable. The shore plain, inside of it, is evidence that no extensive degradation has taken place over the surface of this plain since it was formed. It may be that we must look far back into the history of Kauai for its explanation, to a period before the material of the present mountains was ejected, when an earlier cone was broken down, and this ridge was left, as Somma antedates the present cone of Vesuvius. In this case the shore plain must have derived its lavas from the volcanic mountain which subsequently rose.

The Interior of Volcanic Mountains.

Dissected volcanic mountains, like Kauai, reveal facts with regard to the earlier progress of the cone — that is, the earlier work of the volcano — which in some cases enable the investigator to mark off stages in its history. The island of Kauai, therefore, deserves study, as much as the more famous Hawaii at the other end of the group. One significant fact observed by the author in 1840 has been mentioned, — the much greater thickness of the streams or layers of lava in the interior, — a thickness of a hundred feet occurring within five miles of the sea. The observa-

tions of the author the previous year on Tahiti had proved that island to be essentially the remains of a single great volcanic mountain, the stratification along the sides of the valleys having a regular dip of usually 3° to 5° seaward (see map of Tahiti, p. 375). Moreover, the fact was observed that the "layers become thicker toward the interior." It is stated in the author's "Report" that "five or six miles from the sea, bluffs of a thousand feet constitute apparently a single continuous bed, or at least there is no line of demarcation separating it into parts. Not unfrequently the whole height exhibits a continuous columnar structure throughout." In the face of one precipice in the Matavai valley about five hundred feet high, where the columnar structure was displayed with considerable perfection, the columns, which were ten to twenty inches in diameter, were at several places converged to a point and then restored to parallelism. The breadth occupied by one of these converging clusters was about ten feet; but others were larger.

The conclusion follows that the volcano in its earliest outflows poured out its deepest floods, and afterward the shallower streams, producing the ordinary thin-stratified structure of the exterior and border region.

Tahiti illustrates other points with regard to the occasional, if not common, condition of the central region of the greater volcanic mountains, — that is, the region of the lava-column. The author observes[1] that "in the lofty peak of Orohena the massive structure is still more remarkable. In the view from the top of Aorai (figure on p. 378) a surface of three to four thousand feet is exposed, almost bare of vegetation, and throughout it no trace of layers was detected. Instead, indications of a columnar structure were observed. It was owing, apparently, to this even continuity of surface that the usual amount of vegetation was not spread over it, for there was

[1] Exploration Expedition Geological Report on Tahiti, Bolabola, Maurua, pp. 294, 301, 305; New South Wales, p. 498.

only here and there a crevice that could sustain even a bush."

Further, the thick layers of the interior differ from the thin-bedded in being much less vesicular, and "usually compact with only minute cellules, if any." Six to eight miles up the Papenoö valley rounded stones of a whitish crystalline dioryte-like rock were found by the author, which must have come from some of the central heights; and they suggested the view that the massive character of the rock, through thousands of feet, was due to the cooling, on the decline of the volcano, of the great central mass of lava, or that of the lava-column; and that the coarse crystallization of part of the rock was owing to the extreme slowness with which cooling in so thick a mass would go forward. On the island of Bolabola, another of the Society group, Ellis found, he states, "masses of rocks composed of feldspar and quartz;" and on Maurua, a species of granite is reported as being in considerable abundance. The author's "Expedition Report," in citing these facts, adds that the rocks are very similar to a grayish white feldspathic rock observed by him at Prospect Hill, in New South Wales, which there graduates through porphyritic kinds into an ordinary black basalt.

Such facts led the author in 1839 and 1840 to the conclusion, which he has ever since held, that grade of crystallization in crystalline rocks is an expression of rate of cooling; that "although the liquid rock of volcanic outflows generally cools without distinctly visible crystallization, or with only crystals of feldspar, or of augite, in a compact base, "the cooling is sometimes sufficiently gradual to allow of the whole crystallizing; and in this case the texture throughout is crystalline and the rock much resembles a granite." And further, that "particular crystalline rocks have no necessary relation to time on our globe, except so far as time is connected with a difference in the earth's temperature or climate, and also in oceanic or atmospheric pressure; for if the ele-

ments are at hand, it requires only different circumstances as regards pressure, heat, and slowness of cooling, to form any igneous rock the world contains."[1] Thanks to the investigations of Allport and Judd, and in this country of Messrs. Hague and Iddings, this not hasty inference is now an *established* fact in the science of igneous rocks.

Elevation of the Island.

Kauai has its growing coral-reef and its elevated reefs, and in these respects resembles Oahu.

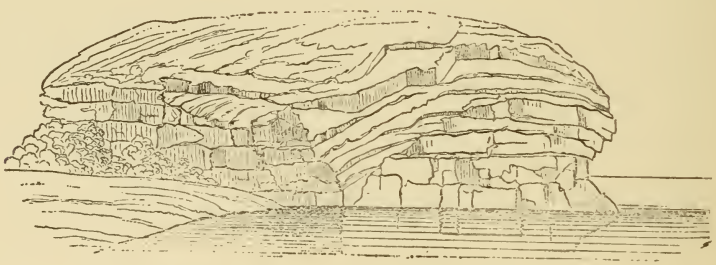
The growing reef is narrow, and is absent altogether on the side of the mountain cliff, where the depth is too great. The beaches of coral-sand are quite extensive on the eastern or windward shores. A low beach-made ridge continues along them, seldom interrupted, which is raised from ten to twenty feet above high tide, and in some places, where drifted by the winds, thirty to thirty-five feet. About the mouths of the streams the sands are often thrown up so as to close the stream entirely, as far as appears at the surface, and deltas of small extent are sometimes formed, as off the mouth of the Hanalei valley, at Anahola, and at other places.

The deposits contain, in some parts, the shells and corals of the present shores but little altered, and resembling beach-worn specimens. There is a small bank of this kind near the mouth of the Hanalei River, four or five feet above the existing level of the sea. But such beds of shells are not common, and by far the greater part is without a fragment larger than a grain of sand. It is remarkable, also, that these sand deposits, formed at the mouth of a river fifty yards wide, should be nearly pure from mountain detritus. The hills, two to three miles back, are covered with loose soil, and the banks of the stream, beyond the termination of the coral-sand deposit, consist of soft earth from the adjoining declivities; yet

[1] Exploration Expedition Geological Report, pp. 377, 378.

it is rare to find a basaltic pebble in the layers, and there is but a trace of earthy material. A few scattered points of a brown color and some of chrysolite may be detected. Facts of this kind show how uncertain is the evidence which a particular deposit may present with regard to the nature of the surface of the country adjoining, or the amount of life in the waters. The fact stated is actually no more remarkable than the freedom of the present beach from basaltic material, for all these accumulations have had a beach origin.

There are also solidified beach-deposits analogous to the drift sand-rock of Oahu, and as remarkable in character. One of the ridges on the shores of the Koloa volcanic district is here represented. It forms a cliff of thirty-five feet; the



Bluff of Calcareous Drift-sands.

cliff appears to be undergoing degradation from the action of the sea, and masses of large size are now lying at the foot. The ridge consists of a laminated calcareous rock, the thin layers of which lap over the ridge, exhibiting full proof of its drift origin. The dip, where greatest, amounts to twenty-five degrees. In some parts the rock is compact and impalpable; but generally it has a sandy texture, though seldom friable. The rains have worn or eroded the surface quite largely; but in some places, where the waters have stood in cavities, the interior of the cavities has become hardened by infiltrating lime, and bowl-shaped depressions have been formed, lined with a crust of compact limestone three fourths of an inch thick and having no trace of a sandy structure.

This ridge is evidence of a change of level in the island of Kauai, though to what extent is not yet known. It was probably about as great as that of Oahu.

B. NIHOA, OR BIRD ISLAND.

The island of Nihoa is a remnant of a small half-submerged cone, fifty-two hundred feet long and sixteen hundred feet in mean width, situated about three hundred miles west-northwest from Kauai. It was surveyed in July of 1885 by Rev. Sereno E. Bishop, acting as assistant in the Hawaiian Government Survey; and the following facts are from his report: —

The island appears to be made up of the north side and of a portion of the east and west sides of a relatively small cone. The sea occupies its open centre in a large bay. From this bay there is for the most part an abrupt rise of forty to two hundred feet, and then a gradual rise to the summit of the cliffs which face the sea on the east, north, and west sides. The highest part to the northwestward is 900 feet above tide-level, and to the northeastward 869 feet.

The island consists of scoriaceous layers made of well-cemented fragments, and has much loose scoria over the ashy soil of the surface. It is intersected by a great number of perpendicular dikes, "perhaps forty or fifty," from two to ten feet wide, having a nearly parallel course from east to west. Soundings about the island are required to obtain an idea of the form and size of the volcanic mountain of which it is a summit cinder-cone.

The island of Kaula, twenty miles southwest of Niihau, was found by Mr. Bishop to be a cone of cinders or tufa, much like Punchbowl on Oahu; and Lehua, an island near the north shore, was of the same general character. Kaula and Lehua are probably lateral cones of Niihau, made by submarine eruptions.

IV. PETROGRAPHY OF THE HAWAIIAN ISLANDS.

BY EDWARD S. DANA.

For our present knowledge of Hawaiian lavas we are indebted in the first place to the general descriptions of J. D. Dana in the "Geology of the Exploring Expedition" (1849), and W. T. Brigham in his "Notes[1] on the Volcanoes of the Hawaiian Islands" (1868); also C. E. Dutton (1884) and others. On the other hand, on the petrographical side, there have been published the microscopic study of basaltic glass of Hawaii, especially Pele's Hair, by Krukenberg,[2] in 1877; a paper by Cohen,[3] devoted chiefly to the glassy basaltic lavas of Hawaii; brief descriptions of isolated specimens of nepheline basalts believed to have come from Oahu, by Wichmann[4] and by Rosenbusch;[5] finally, a recent memoir by Silvestri,[6] describing a series of ancient and modern lavas from Kilauea collected by Professor Tacchini in 1883.

The specimens — the results of whose study are detailed in the following pages — were collected by Prof. J. D. Dana on his trip to the Hawaiian Islands in 1887, and by the Rev. E. P. Baker, of Hilo, in 1888. The former were from Kilauea and parts of the coast region of Hawaii, and from Maui and Oahu; the latter chiefly from the summit region of Mount Loa, and the summit crater Mokuaweoweo, but partly also from the cavern near Hilo, in the lava-stream of 1880–1881, remarkable for its stalactites, of which many fine specimens were included.[7]

[1] Memoirs of the Boston Society of Natural History, vol. i. part iii.

[2] Mikrographie der Glasbasalte von Hawaii, petrographische Untersuchung von C. F. W. Krukenberg, Tübingen, 1877. Also see preceding page 161.

[3] N. Jahrbuch für Mineralogie, etc., 1880, ii. 23.

[4] Jahrbuch, 1875, p. 172.

[5] Mikroskopische Physiographie der massigen Gesteine, 1877, p. 510.

[6] Comitato Geologico d' Italia, Bolletino, 1888, xix. 128–143, 168–196.

[7] Mr. Baker's extended trip over Hawaii, which comprised, besides an exploration of the summit crater, a visit to the sources of several of the great lava-streams,

Mt. Loa: Lavas of its Summit Crater, Mokuaweoweo, and of its Lava-streams.

Of the summit specimens collected by Mr. Baker, a considerable part are from the talus within the southern crater of Mokuaweoweo against the neck between it and the central pit. (See Plate X.) A number of others are from the eastern side of the central pit; and in the case of scattering specimens, the special source is mentioned more minutely beyond, when interest seems to attach to it.

In general it may be said that all the specimens in hand from Mount Loa belong to the same class of basaltic lavas, although they vary widely: in color, from dark gray to light gray or dull brick-red; in structure, from compact to highly cellular or vesicular, and from those of uniform grain to those which are prominently porphyritic with chrysolite or feldspar; and in composition, from the very highly chrysolitic kinds to the feldspathic or augitic forms with little or no chrysolite. Specimens of pumice-like scoria are largely represented in the collection.

The specimens may be divided pretty sharply into two groups; and besides, there are several other types more or less distinct from these.

Clinkstone-like Basalt. — The first of these doubtless includes the rock which former observers have spoken of as resembling phonolite. Microscopically it has a uniform fine-grained texture, for the most part free from vesicles and apparently compact, though often found on closer examination to be minutely porous. The color varies from a dark bluish-gray to light gray, and to dull brick-red or brown, the grayish

was undertaken in order to make the collections of rocks and gather facts with regard to the eruptions, and some extracts from his notes are published in the "American Journal of Science," xxxvii. 52. The results have proved to be of very great interest. The specimens number about seventy, exclusive of the scoria and pumice, and of these fifty have been subjected to microscopic study.

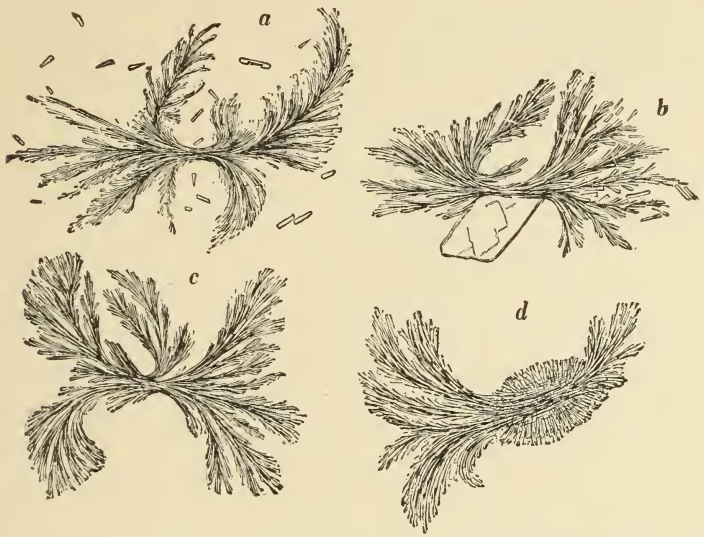
kinds being the most common. The specific gravity varies from 2·82 to 3·00. Some of the separate determinations on fragments freed from air by boiling are, — 3·00, 2·94, 3·00, 2·87, 2·82, 3·00, 2·82. Many of these specimens, as taken from the talus between the central and southern craters, are in the form of thin slabs, and their resemblance to clinkstone in the hand specimen, though not going beyond external aspect, is sufficiently close to explain their having been so named. As regards composition the rocks of this type are most strongly marked by the fact that the chrysolite, which is so common in large grains in the other specimens to be described, is absent or only sparingly present.

The microscopic characters of this group of fine-grained compact rocks are also such as readily to distinguish them from the other forms. In general, they consist of augite and plagioclase, with titanic, or magnetic iron, or both, prominent, but with little or no chrysolite. Their most interesting feature is the form taken by the augite, which is only exceptionally developed as an idiomorphic constituent, but on the other hand is not simply a formless substance filling the spaces between the feldspar. It is uniformly, though with varying degrees of distinctness, grouped in radiating forms, fan-shaped or feather-like, of great variety and beauty.

This structure is eminently characteristic of this group of rocks. It is shown best in a fine-grained purplish-colored specimen (G. = 2·82). This is seen under the hand-glass to be minutely porous though not properly vesicular, with minute slender red crystals (augite) projecting into the cavities. An occasional grain of chrysolite can be detected in the mass, and cleavage sections of feldspar are also seen. Under the microscope it is made up of lath-shaped feldspar individuals and the beautiful groupings of augites, these set out in relief by the fine grains of iron ore surrounding them. In the simplest cases the augite is bunched together in long parallel groups, slightly diverging at the extremities; gener-

ally these branch off at various points into feather-like or dendritic forms, of such variety as to be beyond description. Groups of these forms radiating from a centre are common.[1]

1.



FEATHER-LIKE FORMS OF AUGITE: *a* (× 35), *b* (× 35), *c* (× 50) from Mokuaweoweo, *d* (× 70) from Kilauea.

The accompanying figure (1) shows several of the more complex of these forms (*a*, *b*, from the same specimen), and gives a fair representation of this remarkable structure. Fig. 2 gives the appearance of the entire field of the microscope, showing forms like the frost crystals occasionally seen on a stone pavement; this figure is simplified by the omission of some of the less defined parts.

Some of the simpler rosettes are made up of both feldspar and augite, alike radiating from a common centre; and fre-

[1] Mr. H. Hensoldt, of New York, has called the writer's attention to an augitic lava from Tahiti, in which a pinkish, pleochroic augite is present in radiating groups of acicular crystals, often having a nucleus of chrysolite. The section is one of very exceptional beauty and interest, although the arrangement of the augite is hardly to be compared with that here described, since the individual crystals are sharp and geometrically grouped, — after the manner of the tourmaline in luxullianite, — which is in marked contrast to the feather forms of the Mount Loa augite.

quently the extremities of the feather ends are feldspar individuals. Fig. 3 gives a detailed drawing of part of one of

2.

FEATHER-AUGITE IN BASALT from Mokuaweoweo (× 60).

3.

DETAILED DRAWING SHOWING THE FEATHER-LIKE GROUPING OF AUGITE AND FELDSPAR (× 100).

the groups. It would seem that the feldspar was, as usual, first separated, and the augite, as it crystallized out into these dendritic forms, drew the feldspar needles into position with it. The two minerals are sometimes so intricately involved with each other that it requires close examination to separate them. In polarized light the distinction comes out more sharply.

Occasionally the feldspar is present in larger forms; and more interesting to note is an occasional augite crystal (Fig. 1, *b*) that evidently belongs to an earlier generation, and shows the distinct cleavage, and more or less also the crystalline outline of the species. The alteration to which this specimen, with others like it, has been subjected, and to which the red or purple color of the rock in the mass is due, has stained the iron red, and reddened also the augite, although only exceptionally to such an extent as to make it opaque. The alteration spoken of may be simple weathering, although the occasional brick-red color rather suggests the

action of hot water or steam; the feldspar remains perfectly clear and unchanged.

From the specimen described, which may be taken as the type, we pass to the coarser-grained kinds on the one hand and to the very fine-grained on the other; both of these still retaining, however, the same general characters. A highly cellular specimen (No. 74) with large vesicles, from the northwest brink of the crater, departs in general aspect most widely from the type; but while relatively coarse-grained, it exhibits the same grouping, though somewhat more rigid and geometrical, and shows even more clearly the mutual relations of the feldspar and augite. In the finer-grained varieties the augite sometimes predominates so largely that the whole becomes like a confused carpet pattern of interlacing arabesque forms, though here, when an individual form can be traced out, it has great beauty and perfection, branching and rebranching like some delicate forms of vegetation. Fig. 1, *c*, is an attempt to illustrate one of these forms, but it lacks the delicacy of the original. These forms consist almost exclusively of augite, with very little feldspar. In another specimen of similar character a partial fluidal structure was noticed in the arrangement of the feldspar.

When the iron grains are only sparingly present, and there has been no conspicuous alteration, the rock is of a light uniform gray; but the presence of iron in large amount makes it nearly black and obscures this structure; and when it and the augite are highly altered, the rock is a bright brick-red, and in a section appears as a collection of nearly opaque red rosettes, the feldspar, however, still remaining clear. Glass is present occasionally, but usually in insignificant amounts, and for the most part it is nearly or quite absent. This feather-form of augite which has been described is not entirely confined to the clinkstone-like varieties of lava, although eminently characteristic of them. It was occasionally noted more or less distinctly in some other

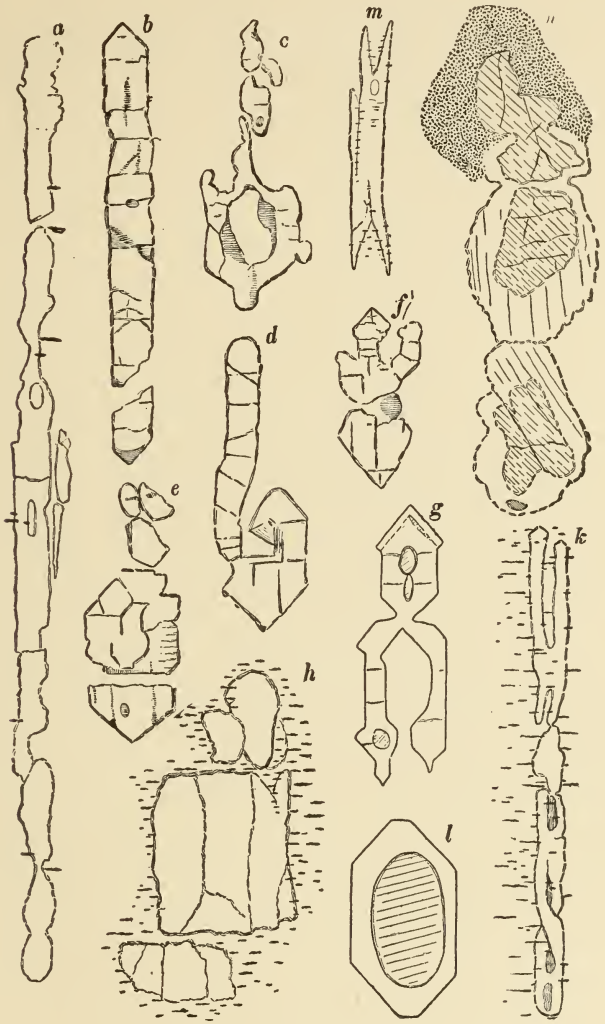
forms, especially the vesicular kinds to be mentioned later (p. 329), where it is seen in the minute second-generation augite which formed in the last process of consolidation. All the facts observed serve to connect its formation with rapid cooling.

Chrysolitic Basalt. — The second group of rocks makes a very marked contrast with those just described. These are of coarse grain, often open-cellular, and very highly chrysolitic; on this account the specific gravity is much higher, it varying from 3·00 to 3·20.[1] In many cases they have suffered some alteration which has given them a dull waxy surface, while the large grains of chrysolite are frequently iridescent, and sometimes have an almost metallic lustre. The color varies with the amount of iron-oxidation from light gray to dull reddish gray or brown. The mineral constituents present are those of normal basalt; and most prominent among these is the chrysolite; in some specimens it must make up nearly half the mass of the rock; and in one case probably more, this particular specimen having the unusual specific gravity of 3·20. The chrysolite was evidently early separated from the magma, and the changes of condition through which the lavas have passed is well shown in the irregularly corroded or occasional broken form of many of the crystals and grains. Even when there is a distinct crystalline outline it is not a rare thing to find the crystal broken and the parts slightly separated. This is shown in the accompanying figures (4, *a* to *f*). Some of the corroded forms take very fantastic shapes. A novel and common feature of this chrysolite is the occurrence of very slender acicular forms. The length is often considerable, even when viewed microscopically, — in one case two to three millimetres, — but in breadth they are often hardly more than a line (note Fig. 4, *a*). This chrysolite shows the partial

[1] Some of the separate determinations gave 3·09, 3·18, 3·09, 3·04, 3·00, 3·20, 3·00.

alteration alluded to in a broad rim of brown iron oxide; we can pass in the same slide from a crystal still preserving its

4



CHRYSOLITE in part with orientated titanic iron; *a–f* (× 55–60), from crystalline basalts of Mokuaweoweo; *g* (× 75) from basaltic glass, Mokuaweoweo; *h* (× 60), from Nanawale; *k* (× 60), Kilauea; *l* (× 100), crystal enclosing glass, Kilauea; *m* (× 60), forked form, Maui; *n* (× 60), portions of crystal enveloped by augite and clusters of magnetite grains, Maui.

transparency throughout to those where only a string of chrysolite grains marks the position of the original individ-

ual, and from these to the cases where a narrow brown line of iron oxide alone is left; in a few cases the chrysolite is stained bright red, showing that there has been oxidation of the iron without hydration.

The orientation of these peculiar rod-like forms, which are distinctly visible on a polished surface of the rock, is a matter of some interest. The fact that in such a form as that of Fig. 4, *b*, and others like it, the plane of the optic axes is transverse to the longitudinal direction and the bisectrix normal to the surface presented, shows that they are elongated in the direction of the vertical axis, the narrow dimension being that of the macrodiagonal. This chrysolite has often an unusually deep green color, possibly connected with the partial alteration, and then shows distinct pleochroism with the absorption least in the direction of the vertical axis. It often shows spherical inclusions of a pale brown glass, sometimes arranged in parallel lines.

The plagioclase feldspar is present in the ordinary forms, and shows no unusual features. The augite forms irregular grains crowded among the feldspars. Occasionally augite in larger more distinctly crystallized forms appears, evidently belonging to an earlier generation. This earlier augite shows the tendency, often observed, to cluster about the chrysolite grains. The titanic iron is not as a rule abundant, and for the most part appears in long slender rods, often parallel among themselves over a limited area, and sometimes orientated by the chrysolite. In two or three of the specimens of this class the augite shows a tendency to assume the radiating form; but this is the exception. Apatite is probably present in some sections, but only in small amount, and in most cases it was not detected. Glass is almost entirely absent from these rocks.

The occasional fractured character of the chrysolite has been spoken of; one specimen shows this in an extreme degree, the chrysolite being separated here into many angular fragments, for the most part showing no crystalline outline.

The feldspar and augite individuals have also suffered in the same way, and the ground mass has a curiously mottled microcrystalline structure suggestive of some porphyry. This specimen stands comparatively alone, although two or three others are of somewhat similar character.

The lavas of the summit containing the most chrysolite were obtained, Mr. Baker states, from the southern border of the crater.

Lavas with minute Crystals of Feldspar and Augite in their Cavities. — Allied to this second class of rocks just described are a number of specimens which are interesting because of their remarkable crystalline structure. One of these is a light gray rock, with only occasional vesicles. It is, however, throughout open and porous, with minute cavities into which project thin tabular crystals of feldspar seen distinctly with a strong hand-glass. A light yellowish augite is also observed, but the crystals are less distinct. Iridescent grains of chrysolite are scattered through the mass, and the fractured surface shows the same long lines of this mineral that are seen in the sections.

An interesting feature of this specimen and of others like it (including one very similar collected two or three hundred feet below the summit of the wall making the east-northeast side of Kilauea, called Waldron's Ledge, also others from Makaopuhi) is the presence in cavities of a mineral of a milk-white color in very minute nearly spherical forms. These are rather abundant through the mass of the rock, each little cavity containing one or two of them. They are so small (rarely more than ·2 or ·3$^{mm.}$ in diameter) that it is very difficult to determine their form, especially as the crystalline faces are dull and give almost no reflections. A hexagonal outline can usually be made out, and occasionally a triangular face through which the angle of another crystal sometimes projects, as if they were complex penetration twins, which the nearly spherical form also suggests. Only one of these forms

was detected in the thin sections, and the free side of this had a hexagonal outline, the whole being divided into sectors which alternately had like extinction, the surface of the sector being mottled in polarized light after the manner of some crystals showing anomalous optical double refraction. The fact that these little white spheres occur also on the inner glazed surface of the vesicles would seem to mark them of subsequent origin, and hence probably zeolitic. Their form suggests a rhombohedral zeolite grouped like phacolite or the Australian herschelite. Two or three other zeolitic minerals were observed in isolated cases, but too sparingly and in too minute forms to be satisfactorily identified.

In other specimens of this class the color is somewhat darkened because of slight alteration, the texture is coarser, and the cavities larger. Here the clear glassy feldspar tablets are very distinct; and augite crystals, red or brown on the surface and opaque, also project into the cavities. Octahedrons of magnetite are often seen implanted upon the augite needles; and broad plates of titanic iron, with rhombohedral planes on the edges, sometimes attain a relatively large size. The feldspar tablets were here large enough to allow of their being separated and examined optically. In form they are either rhombic or acute triangular in outline, being bounded by the planes c (001) and y ($\bar{2}01$) or c and x ($\bar{1}01$), with the prisms very small when present at all. They can often be seen to be twins in accordance with the usual albite law. The extinction on the clinopinacoid made an angle of $-14°$ to $-15°$ with the basal edge, which conforms to typical labradorite, as might have been anticipated. These highly crystalline specimens are also much like some of those collected from ejected masses about Kilauea, and they may here have had a similar origin.

All the specimens that have been thus far described were obtained with a single exception (No. 74, already located) either from the talus in the southern crater against

the wall of the neck that joins it with the central pit, or else from the east side of the interior of central Mokuaweoweo. Nothing can be said in regard to the relations in place of the two types of basalt, which have been described, and which occur together at the points mentioned.

Other Varieties of the Lavas. — A number of the specimens cannot be classed in either of these two groups. They are light gray in color, not vesicular, and sparingly provided with chrysolite, if it is present at all, and characterized by a very uniform granular mixture of augite and plagioclase. A specimen taken from a vein in the western wall belongs here, also another stated to have come from the highest point on the edge of the crater. Still another specimen from the north brink is similar, but is porphyritic with patches of a glassy plagioclase.

Another group of specimens, differing in aspect widely from those described, although not essentially so in composition, are the highly vesicular kinds, sometimes coarsely vesicular, and again with very minute cavities. They have for the most part a common character. Large grains of chrysolite are usually present, often very large in comparison with the size of the vesicles themselves, and with these also are sometimes large crystals of augite and feldspar, often grouped together. The ground-mass filling up the space between these first separated constituents is a dark fine-grained mass of plagioclase and augite with minute grains of iron sometimes so abundant as to render the whole nearly black and opaque. The augite sometimes shows a tendency to group itself in the radiating forms already described. A fluidal arrangement of the feldspar is the exception, though occasionally observed in indistinct form. Only in rare cases is the whole mass of the rock made up of this fine-grained mass without the large crystals. A specimen from the source of the 1843 flow belongs here.

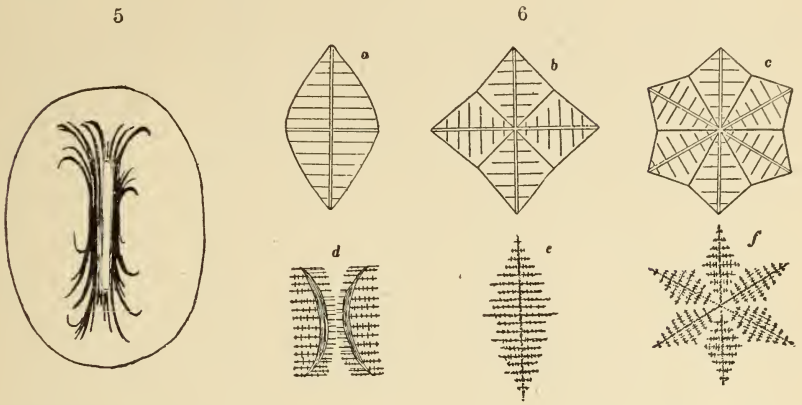
A specimen which is described as the "ordinary ancient

lava of the eastern brink of the crater" is a dark-colored, coarsely vesicular rock (G. = 3·00), with chrysolite abundant in large grains, and augite and feldspar also in large individuals; the amount of the fine-grained dark base of later formation is relatively small, and the augite is somewhat radiated. A peculiar feature of the section is the inclusion by the augite of large plagioclase individuals not regularly orientated, and giving the whole augite a peculiar mottled appearance.

Specimens of Glass. — The Mount Loa collection includes a large number of specimens of the scoria, many pumice-like specimens, some of them of extreme lightness, and also specimens of glass. Several of the glassy kinds were examined microscopically. One of them was a dense black compact mass, uniformly glassy on one side, but on the other largely devitrified; the smooth surface of the glass was roughened by minute projections due to the chrysolite crystals. Its specific gravity is 2·91. Under the microscope the glass had a uniform brown color and amorphous character, except for numerous minute doubly refracting points scattered through it. Here and there were clusters of small chrysolite crystals, having sharp outlines, and perfectly clear except for occasional inclusions of the glass and minute black iron crystals.

A section cut transversely showed with great beauty the gradual transition from the amorphous glass to the largely devitrified lava. The pale yellow-brown glass of the border contained here and there elongated microlites, of dark brown color, due to the glass immediately surrounding them, and also minute crystallites like those described below. In the intermediate zone the microlites were more numerous, and were surrounded by a brown oval aureole of somewhat deeper color than the rest of the glass, this having a beautiful spherulitic structure in polarized light. The nucleus was sometimes transparent (feldspar), and about this were curious

dark brown processes thrown off in curved lines (see Fig. 5). The highly devitrified portion consisted of a nearly continuous mass of dark brown spherulites, and crowded among



5. Feldspar Microlite surrounded by dark filaments within an oval of brown glass (× 90).

6. Crystallites of various Forms (× 160). All from basaltic glass, Mokuaweoweo.

them numbers of whitish nearly opaque crystallites. Many of the spherulites have a distinct nucleus of chrysolite or feldspar, and sometimes there is a medusa-like mass of dark brown bands radiating out from the nucleus.

The crystallites (see Fig. 6) have sometimes a simple oval form, with a faintly indicated structure transverse to the longitudinal axis; there are also compound forms with axes crossing at 90°, making a four-rayed star (*b*), or at 60°, and these last when repeated making a regular six-rayed star (*c*). Rarely these forms are resolved into a delicate skeleton form of the types indicated in *d*, *e*, *f*, and of many other less regular shapes. Similar forms of "crystalloids" are figured by Vogelsang in Plate VII. of his work "Die Krystalliten."

Chrysolite is distributed through the section in isolated crystals or in clusters. These crystals often enclose a considerable amount of the brown glass, and, while sharp in outline, have sometimes peculiar forms (Fig. 4, *g*), which are

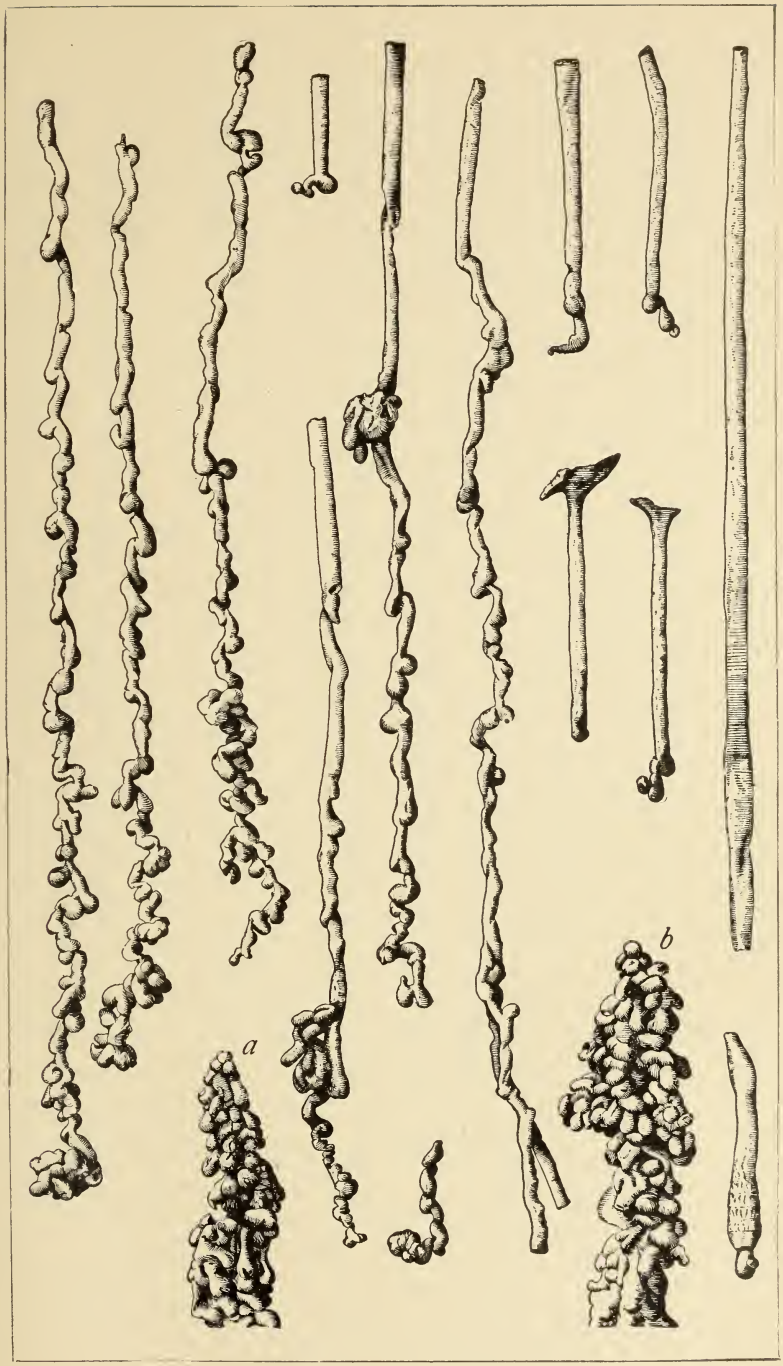
interesting in connection with the corroded forms met with in the highly crystalline basalts which have already been described. Feldspar is present in the more highly devitrified portion; augite not distinctly, except as some of the microlites are to be referred to it.

Another specimen was lithoidal in character, and showed throughout a distinct spherulitic structure. The nearly opaque spherulitic ground-mass contained many light brown transparent spherulites, and grains of chrysolite were scattered through as in the other.

Lava-streams from Mount Loa. — A considerable number of specimens are at hand from the streams of Mount Loa of different dates, and taken from points at various altitudes. For the most part they are simply the surface scoriaceous portions, and consequently without distinctive features. The flows of 1852, 1855–1856, 1859, are thus represented. There are also specimens of the normal crystallized lavas of the stream of 1880–1881 at Hilo; of that of 1843 taken from near its source, which has been already alluded to; and of 1868 and 1887. These are all dark-colored chrysolitic lavas, vesicular in a high degree, especially that from near Hilo (1881), and their characters are those of the vesicular forms spoken of on page 329. The specimens of the flows of 1868 are to be mentioned as particularly rich in chrysolite.

Lava-stalactites from Caverns in Mount Loa Lava-streams.

Perhaps the most interesting and remarkable formations connected with the lava-flows from Mount Loa are the delicate stalactites and stalagmites of lava which occur in the caverns. The specimens in the collection are mostly from a cavern in the lava-stream of 1881 near Hilo, as described on page 209. Figures of some of the forms of similar stalactites



Stalactites from Lava-caverns near Hilo ($\frac{1}{3}$).

from the caverns of Kilauea are given by Brigham, as more particularly mentioned later.

According to the accounts given, the flowing lava-stream, crusted over at the surface, leaves behind it, when the molten material has flowed by, long caverns, usually five to ten feet in height, having a roof of one to three or more feet in thickness and a floor of the solidified lava. In the caverns are found hanging from the roof the slender lava-stalactites. In the Hilo cavern they were from a few inches to twenty or thirty in length, and in some places only six to eight inches apart. The diameter, which seems to have been determined by the size of the drop of the liquid material, does not vary much, being usually about a quarter of an inch. Beneath the stalactites, from the floor below, rise the clustered groups of the stalagmites. These delicate forms are so fragile that they hardly bear transportation, and it is consequently difficult to preserve the longer specimens in their original form. Through the kindness of Mr. Baker the writer has received an admirable series of them, part of which are shown, one third of the natural size, on the accompanying plate. These specimens were collected with great care and skilfully packed in moss, and although fractured at many points when they arrived in New Haven, and thus divided into sections an inch or two in length, it was found possible to cement them together in their original positions.

The general aspect of the stalactites and stalagmites is so well shown in the series of figures on Plate XV. that but little description is needed. It will be noticed that while some are straight and nearly uniform, others are curiously gnarled and knotted, especially near their lower extremities. The end has often a little process thrown off at right angles, a little hook, or a close spiral of two or three turns, often tangled or knotted together. The simple rods are usually round, not often flattened except when there is a sudden change in direction, when they may be pinched together like a glass tube bent

when hot. The surface is exquisitely ornamented with most delicate markings. The stalagmites, formed by the droppings from above, are intricate clusters or piles of simple drops several inches in height, as well represented in Figures *a* and *b* on the plate.

The exterior of the stalactites has usually a more or less bright metallic lustre, and, though sometimes dull and fine granular, the surface often reflects the light brilliantly from a multitude of crystalline facets; these sometimes separate into distinct scales, shown to be largely hematite by their reddish streak, though magnetite is also present. Minute rounded crystals, apparently also of hematite, are sprinkled, often thickly, over the surface. Sometimes the metallic covering is very thin, or is not continuous, forming patches on a brown surface; occasionally at the ends it is altogether absent, and the exterior is thus brown and glassy in aspect, but still retains the polyhedral crystalline aspect; this glass-like crust polarizes light, and is probably augite. Over portions of the rods — and in the case of the straight uniform ones (see the plate) over the whole length — the surface is transversely ribbed or corded in the most delicate manner. The beauty and perfection of these little ripple-marks, as seen under a hand-glass, are beyond description or adequate representation. They are parallel and symmetrical for a limited distance, but vary in fineness

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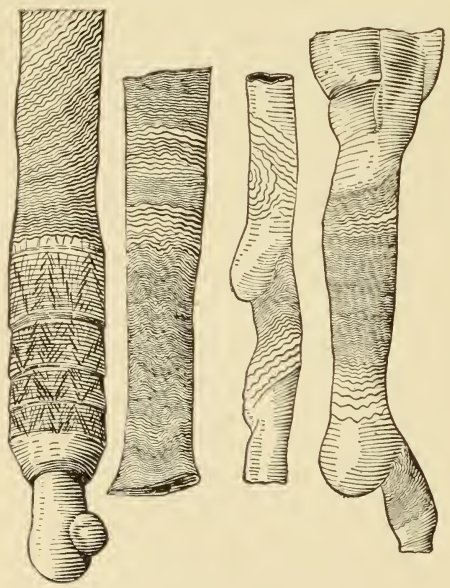

LAVA-STALACTITES ($\times \frac{4}{3}$).

and form with every change in direction of the stalactite itself. Their flow is especially varied about each little projecting knob. Fig. 7 will give some idea of the transverse markings, but details of the structure can hardly be reproduced.

The straighter portions of the stalactites are often solid throughout, though here and there they are hollow and consist of a mere shell. Often portions that are perfectly solid alternate with the cellular parts, or the solid parts contain a series of large vesicles. Fig. 8 gives longitudinal cross sections through a number of typical forms. In *f* the lower cavity was thickly lined with crystals chiefly of feldspar. The exterior crust is seen in the cross section under the microscope to be very thin, and next to it comes usually a narrow but not always continuous band of augite, with occasional iron crystals. The solid parts contain within very slender lath-shaped feldspars of a considerable relative length, often from one quarter to one eighth of the diameter of the stalactite, as seen in a longitudinal section. In one case they showed a marked tendency to parallelism with the axis of the stalactite, but in other cases this was less distinct. A partial concentric arrangement as seen in a transverse section was also noted. The feldspars often have black longitudinal inclusions, probably of magnetite; and their cross sections, square or

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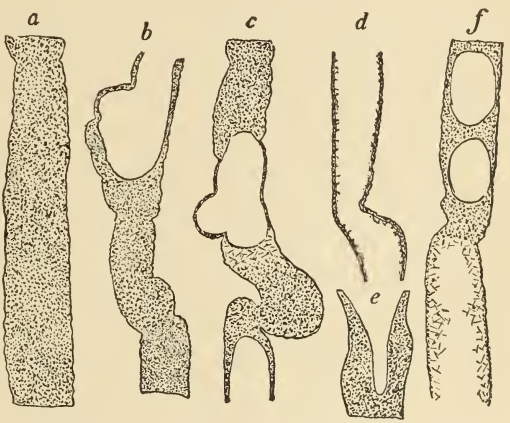
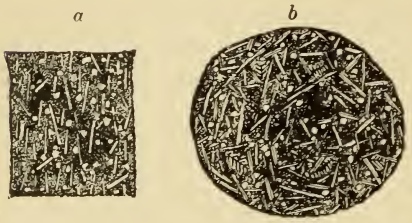


LONGITUDINAL SECTIONS OF LAVA-STALACTITES in outline ($\times \frac{5}{4}$), showing open and solid portions, *a* solid and *d* open throughout, *d* with crystalline lining; the lower part of *f* is thickly lined with crystals, chiefly feldspar.

rectangular in outline, then have a large black centre of the same form. A rather deeply colored greenish yellow augite, somewhat pleochroic, is packed in among the feldspars, and occasionally shows sharp crystalline outlines. There are also numerous grains and octahedrons of magnetite, and throughout a multitude of beautiful dendritic forms branching at angles of 90° or of 60°. This is one of the most marked characters of the sections. The areas, where these iron dendrites are crowded together, are less distinctly individualized, but no glass was noted. Chrysolite is also absent. Fig. 9 (*a* and *b*) will convey some idea of the appearance of the longitudinal and transverse sections. The fact that the structure is throughout coarsely crystalline with the normal constituents of the basalt — except the chrysolite — is an important point.

9



Sections of Lava-stalactites (× 3), *a* longitudinal, *b* transverse (× 5).

The occasional cavities or open spaces in the solid parts of the stalactites are often beautifully lined with large rhombic tables of feldspar, perfectly clear, and so excessively thin as to suggest scales of mica; also dark needles of augite, often curved and wire-like; and octahedrons of magnetite. (See Fig. 8, *f*.) The feldspar plates have mostly the form of a symmetrical lozenge (Fig. 10), with angles of 128° and 52°; one side is shown by the cleavage to be bounded by the basal plane, the other by the dome *x* ($\bar{1}01$). The extinction makes an angle of — 7° to — 9° with the basal edge, which conforms to that of andesine; that is, a plagioclase somewhat more acidic than that determined in the rock mass. These feldspar plates are often marked on

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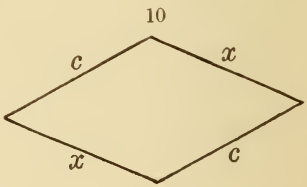


the edges with a thin black scale, presumably magnetite, with numerous minute circular open spaces containing many black points, as if the whole were formed by the drying of little bubbles. The augite crystals are often rough, and black with magnetite.

Where there are vesicular cavities, often filling the whole interior of the tube, these are lined with a comparatively smooth, shining web of feldspar plates and clusters of brown augite crystals, or of augite needles alone, woven together like basket-work. The dull surfaces of magnetite octahedrons are scattered abundantly among the augite and feldspar. The large quantity of magnetite is shown by the fact that the magnet picks up many of the fragments of the stalactites, even when quite large. The specific gravity of fragments of the solid portion of a stalactite was found to be 2·98.

The explanation of the process by which these unique volcanic icicles have been formed is not easy to give. It is clear that further study, on the spot, of their occurrence and the circumstances of their growth is called for. It seems at first most easy to think of them as made by the rather rapid dripping of the semi-viscid lava from the roof. The evidence at hand, however, shows pretty conclusively that they could not have been the result of simple direct fusion. The fact that they hang down from the solid crust, while the stalagmites formed by the dripping from above rise from the solid floor beneath, seems to prove that they were formed after the molten lava had passed by and the temperature had fallen below the point of fusion. If made directly from molten material, they could hardly be so perfectly crystalline throughout as they have been shown to be; we should expect to find them more like the glassy spatterings from the blow-holes of Kilauea mentioned on a later page. Moreover, the sorting out of the material is further evidence on the same side, — the crystalline shell of hematite and magnetite,

with its lining of augite, and within the solid crystalline mass, or the clusters of beautiful crystals chiefly of feldspar. Still again, the question has been raised as to whether the flow of a viscid liquid like the molten lava could form drops so small as the size of the stalactites shows must have been present.

The fact that the lava rods or tubes of the stalactites are of nearly uniform size throughout their length, although bunched and knotted together at frequent points as has been described, is an important one.[1] It separates them, as to mode of origin, from the stalactites of a limestone cavern, which form in a more or less conical shape from the flow down over the exterior surface of the lime-bearing solution. It seems to require that the shell should have formed first, and that these tubes should have lengthened by the material carried down within them, finally resulting in their becoming solid to a greater or less extent. This is confirmed by the fact that the parts seemingly most solid often prove to have at the centre minute crystal-lined cavities. The lengthening by the addition of material at the point of attachment above, the only other method that can be suggested, is difficult to conceive of.

As the facts at hand are inconsistent with the theory of a direct formation from the melted condition, we are forced to speculate as to the power of the highly heated water-vapor, known to be present in large quantities, to form them from the roof by a sort of process of aqueo-fusion. This is a subject about which we know too little at present to make speculation very profitable, and the author prefers to drop the discussion here in the hope that further observations may throw important light upon the matter. The experiments

[1] A stalactite from a Kilauea cavern collected by Prof. J. D. Dana is of interest here, since it forms an exception to those that have been described. About the first-formed stalactite, with its rather thick magnetite shell has been formed a second, somewhat vesicular and nearly concentric with it. This stalactite has the exterior coating of gypsum crystals spoken of by Brigham.

of Fouqué and Lévy in regard to the formation of basalt with their important results, pursued the method of simple igneous fusion; and though Daubrée has discussed the rôle of water in the formation of basalt and basaltic minerals, the investigations thus far made hardly seem to apply very closely to the present case.

The fact that these stalactites occur also in the caverns of Kilauea has already been mentioned. Brigham describes them at some length; and although it is hardly possible to accept all his statements literally, especially as to rate and conditions of growth, his remarks are quoted here at length:[1] —

"A formation which always excites the curiosity of visitors to Kilauea is found in many of the caves in the floor of the crater which have been undisturbed for several years. At first glance the tubes which hang from the roof and the curiously formed droppings beneath these seem to be of igneous origin. An examination *in situ* shows that this was not the case. The roof of these caves is about two feet thick and generally unbroken; the stalactites do not occur under cracks, and indeed there is often no fresh lava over the surface. The formative process may be clearly seen as the tubes form from day to day; and I have caught the steel-gray deposit in the drops on the end of the tubes upon my finger and watched its solidification. Usually the tubes are straight cylinders from one inch to three eighths of an inch in diameter, and sometimes more than two feet long. The bore is almost never continuous; and while externally they are smooth, within a mass of stony cells of considerable size is presented. As long as these tubes grow downward in the quiet upper region of the cave, they hang perpendicularly, but when they reach farther down the currents of air and steam blow the deposits to one side and the tube becomes distorted; it may even return on itself. The drip in the bottom forms much thicker and more irregular stalagmites, as will be seen from the figure, which represents three actual forms, not occurring, however, in the same cave. Specimens have been found which exceed eight inches in diameter, and these are usually low and flat-topped. The more slender ones sometimes rise to a height of two feet; and so

[1] Memoir, pp. 462, 463.

rapidly is the silica deposited that they seldom increase in diameter, but are true acrogens, none of the suspended silica running down the sides. In one cave the growth of the stalactites was at about the rate of an inch a week, but owing to the varying amount of water or steam the production is quite irregular. They are often coated with beautiful white crystals of gypsum, sometimes tipped with needle-like transparent crystals of the same mineral when the cave is high. The natives collect them with the upper open joint of a long bambu."

The following analysis of the solid stalactite, by John C. Jackson, is given by Brigham : —

	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	Na_2O	K_2O	
G. = 2·9	51·9	13·4	15·5	0·8	9·6	4·8	3·0	1·1	= 100·1

Lavas of Kilauea.

The specimens in hand from the volcano of Kilauea, which have been examined microscopically, include four specimens of the recent lava from the bottom of the crater, six specimens of the older lavas, two from Waldron's ledge on the northeast side, and four from the wall west of Halema'uma'u ; finally, a number from the ejected masses on the borders of the crater, especially on the west side. There are also a number of glassy and scoriaceous kinds.

1. *The Recent Lavas.* — The specimens of the recent lavas were taken from the stony part of the layer below an inch or more of glassy crust. They are dark-colored, vesicular basalts, containing chrysolite but not in very large amount. The irregular grains of chrysolite are often aggregated together with augite crystals, and to a limited extent with the lath-shaped feldspars ; these constituents obviously representing those which first separated from the magma. The mass of the solid portion of the rock is of uniform character, consisting of augite and feldspar, with the interstices between them black with the crowded grains or plates of magnetic and titanic iron ; about the borders of the vesicles the iron

is especially dense. It is very interesting to note that these specimens are the only ones among those from Kilauea which show distinctly the stellate feather-like forms of the augite and feldspar so characteristic of many of the Mount Loa lavas (as shown in Fig. 1, *d*, p. 321). The augite forms here are usually smaller and less varied, but there is the same grouping in parallel bundles diverging off at the ends into dendritic forms. The association between the augite and feldspar is also very close, as if the crystallization of the two had been almost simultaneous. Thus the feldspar not only forms in some cases the outer extremities of the feather, but sometimes also is a central rib flanked on both sides by the augite.

Occasionally the chrysolite appears in the long slender forms noted as common among the Mount Loa lavas. One of these is shown in Fig. 4, *k*, which also exhibits the peculiar feature of many of these rocks, often noted in other regions,[1] — the grouping of the titanic iron in parallel position about the chrysolite, normal to the vertical axis. An arrangement of the elongated forms of the titanic iron in parallel position over small areas is sometimes noted where there is no evident relation to the other constituents. Usually, however, the chrysolite is the controlling influence, and the individual often bristles with these little iron rods about its whole outline, as seen in the section. Although these specimens were taken from so near the glassy crust, there is little or no glass shown in the thin section. A specimen from the bottom of the Little Beggar, the lowest part of Kilauea, shows very considerable alteration, the surface being covered, and the vesicles filled with crystals of gypsum ; the mass is rendered red and nearly opaque by the oxidation of the iron.

A specimen of partially devitrified glass shows the presence of spherulites, like those mentioned in similar specimens from Mount Loa, increasing in number where the devitrification is

[1] Cf. Rosenbusch, Massige Gesteine, 1887, p. 722.

most complete. Crystals of chrysolite and microlites of feldspar are also present in large numbers. Some curious specimens from the spatterings about a blow-hole exhibit a vesicular glass with crystals of chrysolite and aggregates of augite and feldspar. The chrysolite encloses large amounts of glass, often in curiously arranged symmetrical bands. One of the crystals is represented in Fig. 4, *l*.

2. *The Older Lavas.* — Of the ancient Kilauea lavas one specimen from Waldron's Ledge is remarkable for its highly chrysolitic character, as its unusual density (G. = 3·18) well shows. It is a grayish compact rock, thickly sprinkled with greenish yellow chrysolite grains. Under the microscope the chrysolite is seen to be in large individuals, usually irregular grains, though also in indistinct crystals and occasional rod-like forms. These often contain abundant glass inclusions. The grains are often packed about with a poorly defined border of augite, and it is in this zone particularly that the little rods of titanic iron are regularly orientated, standing out from the chrysolite in the manner already described. Besides this, it is a granular mixture of augite and plagioclase, not showing any glass. The other specimen from the foot of Waldron's Ledge, is a light-gray cellular rock, highly crystalline, the minute cavities lined by plates of feldspar and tables of titanic iron. It is much like some of the specimens described from Mount Loa (p. 327), and with them is characterized by the same milk-white spherical mineral in the cavities, provisionally referred to phacolite.

The lavas from the west wall of Kilauea west of Halema'uma'u are all closely similar in character among themselves; they are dark-gray in color, vesicular, and contain a fair amount of chrysolite. The structure is throughout crystalline, rather coarsely granular, and the chrysolite is marked by its usual bristling border of titanic iron. One or two of these show something of the radiating augite forms.

3. *Ejected Masses on the Borders of Kilauea.* — The speci-

mens from the borders of Kilauea are supposed to have been ejected at an explosive eruption about a century since. The larger part of the masses are described by Prof. J. D. Dana as being of a fine-grained, gray, slightly vesicular lava. Other specimens are reddish or chocolate-colored, coarsely granular and highly crystalline. In the latter the chrysolite is present in very large amount, and has suffered from alteration, — probably by the action of heated water-vapors, — so that the fractured surface is either dull-red and opaque or else slightly iridescent. The feldspar crystals are clear and glassy, and where there are cavities they often project in distinct transparent plates from the walls. The crystals have an angle of extinction of $-14°$ with the b/c edge, and hence conform to labradorite, like those of similar occurrence among the Mount Loa specimens. Under the microscope the chrysolite is seen to be surrounded with a deep-red border, and the iron oxidation has penetrated into the mass of the crystal, sometimes along broad fracture-lines, and more generally in a network of fine wavy lines, giving it a peculiar feathery aspect. Not infrequently the oxidation has gone so far that the chrysolite is perfectly opaque, and by reflected light is bright brick-red.

Three specimens among the examples of the light-gray lavas have peculiar characters. One is a light-gray rock conspicuous among all those under examination for its beautiful crystalline structure. It is very light and porous, and in each little cavity there are groups of crystals of feldspar in the usual rhombic plates, with minute slender needles of a pale yellow augite iridescent on the surface, and thick tables of titanic iron showing large rhombohedral planes ($cr = 56°$). These last have bright faces, often cavernous, and with a bluish steel-like tarnish. The augites are flattened parallel to the orthopinacoid, as shown by the parallel extinction and the oblique optic axis. Chrysolite is present in the mass of the rock, but hardly appears in the sections. Specific gravity, 3·10.

Another similar rock is more compact, except for parallel lines of cavities partially filled with black glass. A third shows the same structure in part; but the mass of the specimen has a base of a very black glass with crystals of feldspar, augite, and broad plates of titanic iron running through it. In the large cavities the crystals of these minerals project out, though the surface of the cavity is lined with a glassy web. The specific gravity is 3·15. One of the sections under examination is cut across the junction, and shows both the uniform fine-grained crystalline portion and the glassy part with its large enclosed crystals. A curious feature of the glass is the presence of a swarm of minute apatite needles running through it in every direction. These do not extend into the crystallized parts. Apatite usually appears as one of the very earliest secretions from the magma, and why it should be thus localized in these patches of glass while absent from the crystalline parts of the rock it is difficult to explain. In general, apatite has been found to be a rare constituent of the Hawaiian lavas.

Two other specimens are gray compact rocks, extremely fine-grained except for occasional chrysolite grains. Another is peculiar in having small uniformly distributed patches of a dark-colored slightly opalescent glass, which is deep brown, and nearly opaque in the thin section except as it is penetrated by apatite needles, which here also are confined to it.

With the specimen from Kilauea proper belong those collected by Mr. Baker from Nanawale and Makaopuhi, the former chiefly remarkable for their chrysolitic character, the latter sparingly so. Several of the latter specimens are remarkable for that crystalline structure that has been several times remarked upon, and one of them contains the white zeolitic mineral.

Former observers have dwelt at length upon the features of the glassy forms of the lava and the presence of glass in the partly crystalline varieties. This is probably to be explained

by the fact that the specimens which first present themselves to the collector on his visit to the interior of Kilauea are the superficial more or less scoriaceous or glassy forms, which constitute merely a crust, and do not represent the true character of the average lavas. The writer has found glass only a comparatively insignificant element in the normal rocks, and often wholly absent, even from those of recent eruption.

Relation between the Rocks of the Summit Crater of Mount Loa and those of Kilauea.

In general the lavas of the summit crater and of Kilauea, so far as examined by the writer, are strikingly similar in character, all being augitic basalts, varying chiefly as regards the amount of chrysolite present. The clinkstone-like rock of Mokuaweoweo has not been observed at Kilauea; but the feathery grouping of augite and feldspar which characterizes it belongs to the recent Kilauea lavas as well. The darker-colored vesicular basalts, which are highly chrysolitic, and hence of high specific gravity, are alike from both craters. Writers on volcanoes have attempted to draw conclusions in regard to the distribution of the heavier and lighter lavas according to altitude, limiting the former to the lower levels. This is a natural inference on *a priori* grounds; but it does not rest on observation, as the facts already stated sufficiently show. It is a striking fact in connection with the mechanics of volcanic eruptions that lavas of the heaviest character (specific gravity, 3·15 and 3·20) should have been raised to an altitude of nearly fourteen thousand feet above sea-level.

The chemical composition[1] of the Kilauea lavas is well shown by the series of analyses (fourteen in number) given

[1] The remark made by Prof. J. D. Dana must be repeated here, that the early analyses published in the "Geological Report of the United States Exploring Expedition," having been made for him by an inexperienced analyst, are entirely unreliable, and should not be quoted.

by Silvestri, and also those — chiefly of glassy forms — given by Cohen.

Of these analyses three by Silvestri (A, B, C) and two by Cohen (D, E) are quoted here; namely, —

A. Recent vitreous basalt, fresh and unaltered.
B. Older basalt, also fresh.
C. Older basalt, much altered.
D. Compact basalt-obsidian.
E. Pele's Hair.

	A.	B.	C.	D.	E.
	G. = 2·97	G. = 3·01	G. = 2·80	G. = 2·75	G. = 2·66
SiO_2	49·20	48·82	48·60	53·81	50·82
TiO_2	1·72	1·16	. . .	2·01	*undet.*
Al_2O_3	14·90	15·22	25·45	13·48	9·14
Fe_2O_3	4·51	5·72	17·55	3·02	7·33
FeO	12·75	9·65	1·20	7·39	7·03
MnO	0·28	0·67	*tr.*	*tr.*	0·38
CaO	9·20	10·40	2·20	10·34	11·63
MgO	3·90	4·55	0·98	6·46	7·22
Na_2O	1·96	2·10	1·38	3·23	1·02
K_2O	0·95	0·90		0·64	3·06
P_2O_5	0·42	*tr.*	*tr.*	. . .	. . .
H_2O	0·10	. . .	1·87	0·57	1·74
	99·89	99·19	99·23	100·95	99·37

Of other specimens from the island of Hawaii there are two specimens from Punaluu, on the southern coast, — one from the outside of a bomb and the other from an *aa* flow. The interesting point about these is the strongly accentuated flow-structure as shown in the feldspar microlites as they find their way around the occasional large crystals of chrysolite and augite. The fluidal character is as a rule entirely absent from the specimens before described, and in general is not so common in basic as in acidic lavas.

Specimens from western and northwestern Hawaii, Kawaihae, and Mahukono are again more or less vesicular chrysolitic basalts. Of these rocks that from Kawaihae is the most noteworthy because of the large clusters of glassy feldspar crystals, which give it a striking porphyritic aspect.

Lavas of Maui.

From the island of Maui about a dozen specimens have been subjected to microscopical examination, of which three were collected by Rev. S. E. Bishop. The most recent lavas of Haleakala are represented by three specimens, all somewhat scoriaceous. One of these is from the summit at an altitude of nearly ten thousand feet, the others from the bottom floor. They are all very highly chrysolitic, and of high specific gravity (G. = 3·10). The similarity of the hand specimens is so great that they might almost have been taken from the same block. They are dark-colored, very vesicular, and highly porphyritic, with both chrysolite and augite. The large and well-formed crystals of augite often have a narrow external zone of deeper color (violet-brown), and are distinctly pleochroic. They are usually mottled with inclusions of glass or iron. The chrysolite shows but few inclusions. The ground mass is thickly sprinkled with iron grains, making it nearly opaque; small triclinic feldspar needles and a secondary augite in minute form are seen. In these specimens the feldspar must make up but a very inconsiderable proportion of the whole. These recent chrysolitic basalts in Haleakala are much more porphyritic and otherwise quite different from the basalts of Mount Loa and Kilauea.

More different still are several specimens of the older lavas. One of these came from within the crater. It is a very fine-grained, dark bluish gray rock of uniform texture, perfectly fresh, and showing but few minute cavities. It is a feldspathic rock, presenting under the microscope a rather confused aggregation of feldspar and augite, the latter in minute grains, the whole thickly sprinkled with grains of iron. Chrysolite is occasionally noted in peculiar elongated forms, generally forked at both ends, and having a border of titanic iron grains, as before noted (Fig. 4, *m*). The most

marked peculiarity is the presence of minute scales of a dark brown mineral, probably biotite, which, however, is only present very sparingly.

Another interesting specimen (30) which was obtained from the top of Haleakala is a thin, almost schistose rock, light gray in color and presenting the same sort of an aggregation of feldspar and augite under the microscope. Chrysolite, however, is a prominent constituent, especially in the hand specimen. There are also large elongated but usually ill-defined aggregates of magnetite grains marking the presence of original large individuals, biotite or hornblende, which have been re-absorbed into the magma. Occasional remnants of the original mineral are noted, but in very small amount. Another curious feature of this rock is the presence of a zone of augite about the grains of chrysolite. One case of this is illustrated by Fig. 4, *n*. The chrysolite crystal, though separated into different parts, has throughout the same optical orientation, as indicated by the shading, while that of the augite varies from grain to grain. The mantle of magnetite grains about the upper end of the chrysolite seems to represent the remains of the augite which has disappeared. This re-absorption of augite is not commonly observed; but this case, and still more another one where of a single augite crystal alone a large part has disappeared in this way, place the matter above doubt. This zonal arrangement of the augite about the chrysolite has been noted by other observers in a number of cases.[1]

The structure and composition of both these last-mentioned rocks suggest that they should perhaps be classed among the augite-andesites rather than the basalts. To decide this point we have the silica determinations, for which I am indebted to Mr. Henry L. Wheeler, of the Sheffield Scientific School. He found in the first (29) 48·42 p. c. SiO_2, and in the other 50·44 p. c., which conform to that of normal basalt.

[1] See F. D. Adams, American Naturalist, 1885, p. 1087; G. H. Williams, American Journal of Science, 1886, xxxi. 35.

The remaining specimen from the top of Haleakala is a dark gray, almost black rock, of the finest grain, very compact and breaking with a conchoidal fracture. It is characterized by the large amount of iron in minute grains very thickly distributed, so as to make the section nearly opaque unless extremely thin. The feldspar microlites are the most prominent constituent, and these show a rather distinct fluidal arrangement. The two specimens from Paia on Maui are much like those from Haleakala just mentioned, especially No. 29, and like it they bear the same resemblance to andesite. A curious point about them is their readiness to alter, the exposed surfaces passing into a soft earthy mass of a light brown color.

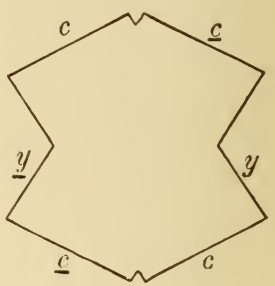
The specimens from Western Maui, collected by Rev. S. E. Bishop, are rocks of peculiar and interesting character. Mr. Bishop says that they are "crusts and soft interiors of the same formation (apparently flowing lava) found on Launiupoko Hill, three miles south of Lahaina. A precisely similar formation occupies the front of Mount Ball, two and one half miles above Lahaina. The crusts are often rolled under the gray soft material. Many crusts of grotesque form lie about, from which the softer part has been washed away. Many portions of the gray soft mass are of great thickness. Much building stone has been hewn from it. It presents no appearances of being the result of any decay, being compact and of uniform texture, except the hard crusts, many of which are crumpled up as if in flowing, like pahoehoe."

One of the specimens (28) is a whitish gray compact rock, whose surface is worn out into a series of deep holes between projecting ridges nearly one inch in height. The texture, though appearing closely compact at first sight, is seen by the glass to be minutely porous, and the surface is speckled with very small rusty spots. Under the microscope it is seen to consist almost exclusively of plagioclase, here and there porphyritically developed; there are also the remnants of a

bright green pleochroic mineral present in traces only, and obviously the original mineral whose disappearance has left the rusty spots; it seems to be hornblende. A little biotite is also present. Iron is scattered through the mass rather sparingly in minute grains; no augite was noted. Another specimen shows the transition from the firm rock to a soft chalky condition powdering under the fingers. The section is very like the other just described, though the feldspar is much clouded and an occasional red crystal of chrysolite is noted.

A third specimen (32) is a flake from a large bowlder (8 × 5 × 4 feet) found one mile southwest of the summit of Mount Ball. Mr. Bishop remarks that in the eroded cliff bowlders occur cemented by mud, being ejectamenta from Mount Ball. The specimen is finely schistose, and so soft and friable as to separate easily into thin silvery scales, and by handling it is soon reduced to a fine powder. Microscopic examination shows it to be very nearly the same in material with the others, but having a distinctly fragmental appearance. There is more chrysolite present in small broken fragments of crystals; there is also a little brown biotite in scales. The mass is made up of penetration twins of plagioclase, according to the Carlsbad law, mostly arranged parallel to the brachypinacoid, and hence showing no other kind of twinning. The form of one of these groups is shown in Fig. 12. The cleavage marks the position of the basal plane, and the angle of the section (about 80°) shows that it is bounded by the planes *c* (001) and *y* ($\bar{2}01$). The extinction makes an angle of a few degrees with the basal edge, varying + or — with a slight change in the direction of the section. This optical character and the further fact that the acute bisectrix is nearly normal to the brachypinacoid would make the feldspar an oligoclase.

12.



Occasional feldspar individuals are cut more nearly parallel to the basal plane, and have the usual elongated form, and show the twinning like the other specimen, but as a rule they all lie nearly parallel to the brachypinacoid. The amount of silica present, as determined by Mr. Wheeler, is 61·63 p. c., which corresponds to the microscopic determination. This remarkable feldspathic andesyte is a totally different rock from any other which has been as yet obtained from the islands, and the writer hopes to be in the position later to give a more minute account of its occurrence and composition.

Lavas of Oahu.

Of the specimens in hand from the island of Oahu, six (33, 36, 40, 41, 44, 45) are from the Kaliuwaa valley, near Punaluu on the north side of the island; four (27, 38, 39, 43) are from the Waialua plain; one (42) from a point just north of Kahuku Bluff; another (37) from a gulch beyond Monolua, four miles west of Honolulu; and, finally, there are a number of specimens of the tufa from the Punchbowl, near Honolulu. Among these specimens, two are forms of highly chrysolitic basalts; these are the specimens from Kahuku Bluff and one of those from near Waialua. In the first of these (42) the chrysolite makes up probably two thirds of the mass of the rock; it is present in distinct isolated crystals, having the characteristic form, each crystal having a rather broad, rusty border, though the interior is for the most part clear and unchanged. The chrysolite encloses grains of iron, but very little glass. The ground mass is a fine-grained mixture of augite and plagioclase with considerable iron, the augite being the more prominent constituent.

In the specimen from Waialua (43) the chrysolite is also prominent; its specific gravity is 3·06. With the chrysolite, the augite and feldspar also occur in large individuals besides being present in the base. The feldspar here contains dark-

colored glassy inclusions in large numbers, arranged parallel to the vertical axis. The base is a confused mixture of dirty brown augite and feldspar, with iron in considerable amount. The specimen (33) from a dike in the upper part of the Kaliuwaa Valley is a very compact, nearly black basalt, unusual in showing occasional grains of pyrite. The feldspar is fresh, but the augite is more or less altered and its place taken by a serpentinous substance, while occasional cavities are filled with a light-colored radiating zeolitic mineral showing feeble double refraction. Besides the usual magnetic iron, which is scattered through in grains or octahedral crystals, there are also curious aggregations of iron ore in very slender rod-like forms, sometimes crossing each other at right angles, but usually matted together with a confusedly reticulated structure, sometimes in spherical aggregates. Specific gravity, 2·90.

Chrysolite is present very sparingly in the remaining rocks, the hand specimen showing only here and there an isolated grain, and sometimes close search is needed to detect it. They are all light bluish gray basalts, with specific gravity ranging from 2·86 to 2·91. No very close study has been made of these specimens, but with a number of them their aspect, their highly feldspathic character, and the microscopic structure made it seem as if they might more properly belong to the andesytes; a silica determination of one of them (36, G. = 2·86) by Mr. Wheeler gave, however, only 50·55 p. c. SiO_2. Several of these rocks show more or less alteration, and in one of them (36) the occasional crystals of chrysolite have entirely passed into serpentine. For the most part they are highly crystalline, but one of the group (45, G.=2·88) shows numerous patches of a dark brown glass; this specimen is the most highly chrysolitic of the number, it being present in minute grains among the feldspar and augite, each grain having its orientated fringe of titanic iron. No nepheline-basalt was detected among the specimens in hand.

BATHYMETRIC MAP OF THE PACIFIC AND ATLANTIC OCEANS

1000 FATHOMS
2000 "
3000 "
4000 "

ASIA
EUROPE
AFRICA
NORTH AMERICA
SOUTH AMERICA
AUSTRALIA
BEHRING SEA
SEA OF OCHOTSK
JAPAN SEA
YELLOW SEA
ALASKA
ALEUTIAN ISLANDS
KAMTCHATKA P.
KURILE ISS.
HUDSON BAY
DAVIS STRAIT
GREENLAND
ICELAND
SCANDINAVIAN PLATEAU
FAROE
SHETLANDS
BRITISH ISLES
NORWAY
SWEDEN
BALTIC
WHITE SEA
BRITISH COLUMBIA
WASHINGTON T.
OREGON
UNITED STATES
CANADA
MEXICO
Boston
N.York
Charleston
Hatteras
BERMUDA
AZORES
MADEIRA
CANARIES
C.VERDES
SPAIN
FRANCE
ITALY
Malta
Sicily
RED SEA
GULF OF MEXICO
CARIBBEAN SEA
Jamaica
Barbados
TRINIDAD I.
GALAPAGOS
Christmas I.
PHENIX Is.
MARQUESAS
PAUMOTU GROUP
Hemuake I.
Tahiti
Ducie I.
Sala y Gomez I.
Easter I.
Rio de Janeiro
Lima
Valparaiso
Buenos Ayres
PATAGONIAN PLATEAU
ASCENSION I.
ST. HELENA
Tristan da Cunha
Gough I.
C. OF GOOD HOPE
FALKLAND IDS.
S. GEORGIA
S. SANDWICH Idss.
S. ORKNEYS
S. SHETLANDS
PALMER'S LAND
C. HORN
Norfolk I.
N.S.WALES
SYDNEY
VICTORIA
TASMANIA
Auckland I.
Campbell I.
Macquarie I.
Emerald I.
Chatham I.
Antipodas I.
Bounty I.
Dougherty I.
Maria Theresa
WAKES I.
CAROLINES
LADRONES
PELEW Is.
MINDANAO
CELEBES
GUINEA
FIJIES
SAMOA
NEW HEBRIDES
NEW CALEDONIA
NEW ZEALAND
HERVEY Is.
TAHITIAN
KERMADEC
GILBERT Is.
RATACHES
RADACS
PAPUA
Ceram
Acapulco
Panama
Gulf of California
Honduras
Maracaibo
Orinoco
Paramaribo
Pernambuco
Bahia
Sierra Leone
Senegal
Canaries
Madeira
Azores
Bermuda
Hatteras
Charleston
N.York
Boston
Labrador
Davis Strait
Greenland
Iceland
Faroe
Shetlands
British Isles
Norway
Sweden
Baltic
White Sea
Red Sea
Malta
Sicily
Italy
France
Spain
Canaries
C.Verdes
Ascension I.
St. Helena
Tristan da Cunha
Gough I.
C. of Good Hope
Rio de Janeiro
Lima
Valparaiso
Buenos Ayres
Falkland Ids.
S. Georgia
S. Sandwich Idss.
S. Orkneys
S. Shetlands
Palmer's Land
C. Horn
Galapagos
Christmas I.
Phenix Is.
Marquesas
Paumotu Group
Hemuake I.
Tahiti
Ducie I.
Sala y Gomez I.
Easter I.
Maria Theresa
Norfolk I.
Auckland I.
Campbell I.
Macquarie I.
Emerald I.
Chatham I.
Antipodas I.
Bounty I.
Dougherty I.
Wakes I.
Carolines
Ladrones
Pelew Is.
Mindanao
Celebes
Guinea
Fijies
Samoa
New Hebrides
New Caledonia
New Zealand
Hervey Is.
Tahitian
Kermadec
Gilbert Is.
Ratachs
Radacs
Papua
Ceram
Kamtchatka P.
Kurile Iss.
Aleutian Islands
Behring Sea
Sea of Ochotsk
Japan Sea
Yellow Sea
Nippon
Formosa
Loochoo Is.
Bonin Ids.
Hawaiian Is.
Yellow Sea
Tasmania
Victoria
Sydney
N.S.Wales
Australia
Papua
Timor
Celebes
Mindanao
Ceram
Guinea
Fijies
Samoa
New Hebrides
New Caledonia
New Zealand
Hervey Is.
Tahitian
Kermadec
Gilbert Is.
Ratachs
Radacs
Marquesas
Paumotu Group
Hemuake I.
Tahiti
Ducie I.
Sala y Gomez I.
Easter I.
Maria Theresa
Norfolk I.
Auckland I.
Campbell I.
Macquarie I.
Emerald I.
Chatham I.
Antipodas I.
Bounty I.
Dougherty I.
Wakes I.
Carolines
Ladrones
Pelew Is.
Mindanao
Celebes

Part Third.

VOLCANOES AND DEEP-SEA TOPOGRAPHY.

IT has become a question of much interest as regards the origin of volcanic phenomena, whether the profound oceanic depths which occur in the vicinity of Hawaii and near some other volcanic islands are a result in any way of the volcanic action, — either through the undermining which the discharge of the enormous amount of material needed to make mountains over thirty thousand feet in height from the ocean's bottom, and 6° to 8° in mean slope, must have occasioned if it were not prevented by a continued and full supply from beneath, or through the gravitational pressure which has been appealed to as the cause of the ascensive force.

But is not this inquiry fully answered by the principle sustained by Darwin, that the regions of volcanic islands in the Pacific are areas of elevation? It would be so if Darwin's conclusion were right. In the study of the ocean's islands and in Darwin's account of them, the author has found no facts that sustain the conclusion. The facts serve to prove, so far as there is any general rule, only that such islands have undergone less subsidence than the area of coral islands.

The longer the continuance of volcanic action the larger becomes the volcanic mountain; and this principle is sufficient to account for the great elevation of the mountains of Hawaii. There is reason for believing that the fires along

the Hawaiian line broke out all together at some time in the long past, but only Hawaii has kept on piling up lava-streams from that remote time of outbreak until now, and hence has come the altitude of these loftiest volcanic mountains of the Pacific; and this in spite, it may be, of much subsidence.

The question of subsidence through volcanic action and its influence on oceanic topography is the subject before us. Its consideration involves a general study of the origin of the ocean's deep troughs; and this demands, as the first step, a general review of oceanic topography, — for according to recent bathymetric investigations, the deep troughs are part of the system of topography, and its grander part. We need for this purpose an accurate map of the depths and heights through all the great area. Such a map will ultimately be made through the combined services of the Hydrographic Departments of the civilized nations. At the present time the lines of soundings over the oceans, especially over the Pacific and Indian, are few, and only some general conclusions are attainable. It is to be noticed that the system of features of the oceanic area are involved in the more general terrestrial system; but since the former comprises nearly three fourths of the surface of the sphere, it is not a subordinate part in that system.

With reference to this discussion of the subject the author has prepared the accompanying bathymetric map.

The Bathymetric Map, and the general Features of the Oceanic Depression displayed by it.

The Map (Plate XVI.). — In the preparation of the bathymetric map the recent charts of the Hydrographic Departments of the United States and Great Britain were used,[1]

[1] The author is indebted to the Hydrographic Departments of Great Britain as well as the United States for copies of these charts.

which contain all depths to date, and the lists of new soundings published in German and other geographical journals. In order that the facts on which the bathymetric lines are based may be before the reader, a large part of the depths are given, but in an abbreviated form, 100 fathoms being made the unit: 25 signifying 2,500 fathoms or nearly (between 2,460 and 2,550); 2·3, about 230 fathoms; ·4 about 40 fathoms. Only for some deep points is the depth given in full. The addition of a plus sign (+) signifies no bottom reached by the sounding.[1]

In the plotting of oceanic bathymetric lines from the few lines of soundings that have been made, the doubts which constantly rise have to be settled largely by a reference to the general features of the ocean, and here wide differences in judgment may exist in the use of the same facts; but through the depths stated on the map, the reader has the means of judging for himself. In the case of an island the lines about it may often have their courses determined by those of adjoining groups or by its own trend; but in very many cases new soundings are needed for a satisfactory conclusion.

Some divergences on the map from other published bathymetric maps require a word of explanation. The northern half of the North Pacific is made, on other deep-sea maps,

[1] On the map the bathymetric lines for 1,000, 2,000, 3,000, and 4,000 fathoms, besides being distinguished in the usual way by number of dots, have been made to differ in breadth of line, the deeper being made quite heavy in order to exhibit plainly the positions of the areas without the use of colors. The line for 100 fathoms is, as usual, a simple dotted line. As the bathymetric map herewith published is necessarily small, and none of the ordinary maps of the oceans give either deep-sea soundings or a correct idea of the trends of the oceanic ranges of islands, I state here that the charts of the United States Hydrographic Department for the Atlantic, Pacific, Indian, and Arctic oceans, may be purchased of dealers in charts in the larger sea-board cities. There are several large charts to each ocean. One of the firms selling them in New York City is that of T. S. & J. D. Negus, 140 Water Street. The occasional bulletins from the Hydrographic Departments of America and Great Britain and Petermann's Mittheilungen contain nearly all the new data issued for the perfecting of such a chart.

part of a great 3,000-fathom area (between 3,000 and 4,000) stretching from the long and deep trough near Japan far enough eastward to include the soundings of 3,000 fathoms and over in mid-ocean along the thirty-fifth parallel. It has seemed more reasonable, in view of present knowledge from soundings, to confine the deep-sea area off Japan to the border-region of the ocean, near the Kurile and Aleutian islands, and leave the area in mid-ocean to be enlarged as more soundings shall be obtained. Again in the South Pacific, west of Patagonia, the area of relatively shallow soundings (under 2,000 fathoms) extending out from the coast is on other maps bent southward at its outer western limit so as to include the area of similar soundings on the parallels of 40° and 50°, between 112° and 122° W. The prevailing trends of the ocean are opposed to such a bend, and more soundings are thought to be necessary before adopting it.

It may be added here that in the Antarctic Atlantic, about the parallel of 66½° S. and the meridian of 13½° W., a large area of 3,000 and 4,000 fathoms has been located. It was based on a sounding in 1842 by Captain Ross, R. N., in which the lead ran out 4,000 fathoms without finding bottom. The sounding was, therefore, made before the means available were "sufficient to insure the accuracy of such deep casts."

The Feature-lines of the Oceanic and Bordering Lands.

The courses of island-ranges and coast-lines have a bearing on the question as to the courses of the deep-sea troughs, and therefore, by way of introduction, they are here briefly reviewed.[1] The system of trends in feature-lines takes new

[1] This subject of the system in the earth's feature-lines is presented at length, with a map, in the author's "Expedition Geological Report," pp. 11–23 and 414–424; and also more briefly in the "American Journal of Science," 1846, 2d series, ii. 381.

significance from a bathymetric map, for the courses are no longer mere trends of islands or emerged mountain peaks, they are the trends of the great mountain ranges themselves; and in the Pacific these mountain courses are those of half a hemisphere. Some of the deductions from such a map are briefly as follows: —

1. Over the Pacific area there are *no* prominent north-and-south, or meridional, courses in its ranges, and none over the Atlantic, except the axial range of relatively shallow water in the South Atlantic. And to this statement it may pertinently be added that there are none in the great ranges of Asia and Europe, excepting the Urals; none in North America; none in South America, excepting a part of those on its west side.

2. The ranges in the Pacific Ocean have a mean trend of not far from northwest by west, which is the course very nearly of the longer diameter of the ocean. One *transverse* range crosses the middle South Pacific, — the New Zealand, — commencing to the south in New Zealand and the islands south of it, with the course N. 35° E., and continuing through the Kermadec Islands and the Tonga group, the latter trending about N. 22° E.; and this is the nearest to north and south in the ocean, except toward its western border.

3. The oceanic ranges are rarely straight, but instead change gradually in trend through a large curve or a series of curves. For example, the chain of the central Pacific becomes to the westward north-northwest; and the Aleutian range and others off the Asiatic coast make a series of consecutive curves. Curves are the rule rather than the exception. Moreover, the intersections of crossing ranges, curved or not, are in general nearly rectangular.

4. Approximate parallelisms exist between the distant ranges or feature-lines; as (1) between the trend of the New Zealand range and that of the east coast of North America;

and also that of South America (which is continued across the ocean to Scandinavia); also (2) between the trend of the foot of the New Zealand boot with the Louisiade group and New Guinea farther west, and the mean trend of the islands of the central Pacific both south and north of the equator, and also that of the north shore of South America. These are a few examples out of many to be observed on the map.

5. The relatively shallow-water area which stretches across the North Atlantic from Scandinavia to Greenland — the Scandinavian plateau, as it may well be called — is continued from these high latitude seas southwestward, in the direction of the axis of the North Atlantic (or parallel nearly to the coast of eastern North America and the opposite coast of Africa), and becomes the "Dolphin shoal."

It may be a correlate fact in the earth's system of features that a Patagonian plateau stretches out from the Patagonia coast, or from high southern latitudes, in the direction of the longer axis of the Pacific, and embraces the Paumotu and other archipelagoes beyond.[2] This Patagonia plateau also extends in the opposite direction over the Falkland Islands and far beyond.

The above review of the earth's physiognomy, if accompanied by a survey of the map, may suffice for the main purpose here in view: to illustrate the general truths, — that system in the feature-lines is a fact; that the system is

[1] As parallelisms may have importance that is not now apparent, I draw attention to one between the Mediterranean Sea that divides Europe from Africa, and the West India (or West Mediterranean) Sea that divides North from South America. Both have an *eastern*, *middle*, and *western* deep basin. Their depths (see map) in the East Mediterranean, are 2,170, 2,040 and 1,585 fathoms; in the West Mediterranean (the three being the Caribbean, the West Caribbean or Cuban, and the Gulf of Mexico), 2,804, 3,428, and 2,080 fathoms. Further, in each Mediterranean Sea, a shallow-water plateau extends from a prominent point on the south side, northward, to islands between the eastern and middle of the deep basins, — one from the northeast angle of Tunis to Sicily, the other from the northeast angle of Honduras to Jamaica and Hayti, the two about the same in range of depth of water. And this last parallelism has its parallels through geological history, even to the Quaternary, when the great mammals made migrations to the islands in each *from the continent to the south*.

world-wide in its scope; and — since these feature-lines have been successively developed with the progress of geological history — that the system had its foundation in the beginning of the earth's genesis and was developed to full completion with its growth.

Facts bearing on the Origin of the Deep-sea Troughs.

In treating this subject, the facts from the vicinity of volcanic lands that favor a volcanic origin are first mentioned; secondly, those from similar regions that are not favorable to such an origin; thirdly, facts from other regions bearing on the question.

A. Facts apparently favoring a Volcanic Origin.

1. The Pacific soundings have made known the existence of two deep-sea depressions, if not a continuous trough, *within forty miles of the Hawaiian Islands*, — one situated to the northeast of Oahu, or north of Molokai, with a depth of 3,023 fathoms, or 18,069 feet; and the other east of the east point of Hawaii, 2,875 fathoms, or within 750 feet of 18,000 feet. Again, 450 miles northeast of Oahu, there is a trough in the ocean's bottom, over 800 miles long, which runs nearly parallel with the group and has a depth of 3,000 to 3,540 fathoms; and, as far south, another similar trough of probably greater length has afforded soundings of 3,000 to 3,100 fathoms. The depths about the more western part of the Hawaiian chain of islands have not yet been ascertained, and hence the limits of the deep areas are not known. Such depths, so close to a line of great volcanic mountains, the loftiest of the mountains not yet extinct, appear as if they might have resulted from a subsidence consequent on the volcanic action.

The subsidence might have taken place (1) either from

underminings, which the amount of matter thrown out and now constituting the mountain chain, with its peaks of 20,000 to 30,000 feet above the sea-bottom, shows may be large; or (2) from the gravitational pressure in the earth's crust about a volcanic region which speculation makes a source of the ascensive force and of the upward rising of the lavas, — the subsiding crust following down the liquid surface beneath. In either case the mass of ejected material might be a measure more or less perfect of the maximum amount of subsidence.

2. In the western part of the North Pacific, at the south end of the volcanic group of the Ladrones, off the largest island of the group, Guam, the "Challenger" found a depth of 4,475 fathoms, one of the two deepest spots yet known in the Pacific. The situation with reference to the group is like that off the east end of the Hawaiian group.

3. In the South Pacific, not far southwest of Tongatabu, the largest island of the Tonga or Friendly group, depths of 4,295 and 4,428 fathoms were obtained in soundings by Capt. Pelham Aldrich, of H. M. S. "Egeria," in latitudes 24° 49′, 24° 37′ S., and longitudes 175° 07′, 175° 08′ W. In latitude 24° 00′ and longitude 175° 16′ the depth found was 3,692 fathoms; in 24° 27′ and 176° 15′, 530 fathoms; in 23° 12′, 175° 40′, 596 fathoms.[1]

4. East of Japan and the Kuriles, a region of ranges of volcanoes, there is the longest and deepest trough of the ocean, first made known by the soundings of the United States ship "Tuscarora;" the length is 1,800 miles, the depths 4,000 to 4,650 fathoms; and farther northeast, south of one of the Aleutian Islands, a depth of 4,037 fathoms occurs again, also obtained by the "Tuscarora;" and depths of 3,100 to 3,664 fathoms exist still farther east. It is probable that the 4,000-line trough continues from the Kuriles

[1] American Journal of Science, 1889, xxxvii. 420, and Bulletin of the British Hydrographic Department of February, 1889.

to this deep spot off the Aleutian volcanic range; and if so, the length of the trough is over 2,500 miles. The map is made to suggest its extension still farther eastward; but among the few soundings made off the more eastern Aleutians, the deepest are 3,664 and 3,820 fathoms, near longitude 165° W. The latter was obtained by the "Albatross," of the United States Fish Commission, in 1888, in latitude 52° 20′ N. and 165° W. Farther west the "Albatross" found, in latitude 52° 18′ N. and longitude 163° 54′ W., a depth of 2,848 fathoms; in 52° 20′ N., 166° 05′ W., 2,654 fathoms; in 52° 40′ N., 166° 35′ W., 2,267 fathoms, — indicating, as the report states, that the depression of 3,000 to 3,820 fathoms is not continued westward.

Other similar facts may be found on the map; and still others may exist which are not now manifest, owing to the sinking of oceanic areas and islands. But no cases can be pointed out which are more decisively in favor of volcanic origin.

B. Facts from the Vicinity of Volcanic Regions apparently not referable to a Volcanic Origin.

The ocean off the western border of North and South America affords striking examples of the absence of deep troughs from the vicinity of regions eminently volcanic. The South American volcanoes are many and lofty; and still the ocean adjoining is mostly between 2,000 and 2,700 fathoms in depth; and just south of Valparaiso, it shallows to 1,325 fathoms. The only exception yet observed is that of a short trough of 3,000 to 3,368 fathoms, close by the Peruvian shore. It may, however, prove to be a long trough, although certainly stopping short of Valparaiso. The waters, however, of the Pacific border of both South and North America deepen abruptly compared with those of the Atlantic border; and the significance of this fact deserves consideration.

The facts off Central America are more remarkable than those off the coast to the south. The volcanoes are quite near to the Pacific coast, and still the depths are between 1,500 and 2,500 fathoms.

The condition is the same off the west coast of North America. Of the two areas of 3,000 or more fathoms nearest to the east coast of the North Pacific, one is 600 miles distant in the latitude of San Francisco, and the other is within ten degrees of the equator and twenty degrees of the coast; both are too far away to be a consequence of volcanic action in California, Mexico, or Central America.

In the North Atlantic the European side has its volcanoes, and has had them since the Silurian era, and yet the non-volcanic North American side of the ocean has far the larger areas of deep water and much greater mean depth. The Azores or Western Islands, which are all volcanic, have depths around them of only 1,000 to 2,000 fathoms and no local troughs. Iceland, the land of Hecla, is in still shallower waters, with no evidence of local depressions off its shores. The Canaries are volcanic, but no deep trough is near them.

c. Facts from Regions not Volcanic which are unfavorable to the Idea of a Volcanic Origin.

1. *In the North Pacific*, near its centre, the area of 3,000 or more fathoms about 35° N.; the two similar but smaller areas toward its eastern border; the areas north of the Carolines, in the western part of the ocean; the broad equatorial area about the Phœnix Group; the area in the South Pacific in 170° W., east of Chatham Island, and another just south of Australia, — are all so situated that no reason is apparent for referring them to a volcanic origin. Some of the areas are in the coral-island latitudes, and the supposed volcanic basis of coral islands makes a volcanic origin pos-

sible; but their probable size and position appear to favor the idea of origin through some more fundamental cause. The area in the South Pacific, east of Chatham Island, is 450 miles distant from the land. The border of southern Australia, abreast of the deep-sea trough, has no known volcano.

2. *In the Atlantic away from the West Indies.* — The 3,000-fathom areas of the North and South Atlantic — that is, the three in the North Atlantic, the two in the South Atlantic, and the two equatorial, one near the coast of Guinea and the other near that of South America — occupy positions that suggest no relation to volcanic conditions. The Cape Verdes, north of the equator, are partly encircled by one of the deep areas, somewhat like the eastern end of the Hawaiian group; but this bathymetric area appears to be too large to owe its origin directly to volcanic work in the group. The coast of Guinea near the 3,000-fathom area has nothing volcanic about it, and the opposite coast of South America, near another, is free from volcanoes.

The only facts in the Atlantic that suggest a volcanic origin are the depression of 2,445 fathoms within forty miles of the west side of the volcanic Cape Verde Archipelago, and that of 2,060 fathoms within twenty miles of Ascension Island; and a connection is possible.

3. *In and near the West Indies.* — The most remarkable of the depths of the Atlantic area are situated in and near the region of the West Indies, as is well illustrated and discussed by Mr. Alexander Agassiz in his instructive work on the "Three Cruises of the Blake." The deepest trough of the ocean (4,561 fathoms) occurs within seventy miles of Porto Rico; and yet this island has no great volcanic mountain, though having basaltic rocks. By the north side of the Bahama belt of coral reefs and islands, for 400 miles, as Mr. Agassiz well illustrates, the depth becomes 2,600 to 3,000 fathoms within twenty miles of the coast-line, and at

one point 2,774 within eight miles, a pitch-down of 1 : 2·5; and nothing suggests a volcanic cause for the abrupt descent. Cuba and Hayti are not volcanic, and look as if they were an extension of Florida, so that no grounds exist for assuming that the Bahamas rest on volcanic summits.

One of the strangest of 3,000-fathom troughs is that which commences off the south shore of eastern Cuba, having there a depth of 3,000 to 3,180 fathoms. It is within twenty miles of this non-volcanic shore, and nearly three times this distance from Jamaica. No sufficient reason appears at present for pronouncing its origin volcanic. It is continued in a west-by-south direction to a point beyond the meridian of 85° W., or over 700 miles, making it a very long trough, and the depths vary from 2,700 to 3,428 fathoms. The depression extends on into the Gulf of Honduras, carrying a depth of 2,000 fathoms far toward its head, and in a small indentation of the coast it stops; for nothing of it appears in the outline of the Pacific coast or the depths off it, and nothing in the range of volcanic mountains on the coast. Against the three deepest parts of the trough there are (1) the Grand Cayman reef, twenty miles north of a spot 3,428 fathoms deep; (2) banks in 13 and 15 fathoms within fifteen miles of a depth of 2,982 fathoms; and (3) Swan Island reef, fifteen miles south of a depth of 3,010 fathoms; the first of the three indicating a slope to the bottom of 1 : 5, and the last of 1 : 4·4. Why these greatest depths in the trough, so abrupt in depression, should be on one side of shoals or emerged coral reefs, it is not easy to explain: and the less so that the part of the trough south of Cuba has nothing volcanic near by in the adjoining mountain range, and the fact also that the westernmost end of the trough extends on for 175 miles, and there has a depth of 3,048 fathoms with 2,000 fathoms either side and no coral reefs.

D. Arrangement of the Deep-sea Troughs in the Halves of the Oceans pointing to some other than a Volcanic Origin.

The *western* half of the Atlantic and Pacific oceans contains much the larger part of the 3,000-fathom areas and all the depths over 4,000 fathoms. In the North Atlantic the areas of 3,000 and over in the western half, or off the coast of the United States, are very large; and the bathymetric line of 2,500 fathoms extends westward nearly to the 1,000-fathom line. This important feature can be appreciated for both oceans from a look at the map, without special explanations.

As a partial consequence of this arrangement, the Pacific, viewed as a whole, may be said to have a westward slope in its bottom, or from the South American coast toward Japan. This westward slope of the bottom exists even in the area between New Zealand and Australia, — the ocean in this area being shallow for a long distance from the coast on the east side and deepening to 2,500 – 2,700 fathoms close to that non-volcanic land, New South Wales or eastern Australia. In the Atlantic the slope is in the direction of its northeast-southwest axis, either side of the Dolphin shoal, but especially the western side, rather than from east to west, it commencing in the Scandinavian plateau and ending in the great depths adjoining the West Indies.

Owing to the system in the Atlantic topography, the Dolphin Shoal — the site of the *Atlantis* of ancient and modern fable — is really an appendage to the Eastern Continent (that is, to Europe), and is shut off by wide abyssal seas from the lands to the west that have been supposed to need its gravel for rock-making.

But the view that the west half of an oceanic basin is always the deepest becomes checked by finding in the Indian Ocean that the only areas that are 3,000 fathoms deep or over are in the *eastern* part of the ocean, off the north-

west coast of Australia, and near western Java and Sumatra. The greatest depths in its western half, or toward Africa, are 2,400 to 2,600 fathoms.[1]

Conclusions.

1. The facts reviewed lead far away from the idea that volcanic action has been predominant in determining the position of the deep-sea troughs. It has probably occasioned some deep depressions within a score or two of miles of the centre of activity, but beyond this the great depths have probably had some other origin.

2. It is further evident that the deep-sea troughs are not a result of superficial causes of trough-making. Erosion over the ocean's bottom cannot excavate isolated troughs. The coldest water of the ocean stands in the deep holes or troughs instead of running, as the reader of Agassiz's volume has learned.

The superficial operation of weighting the earth's crust with sediment, or with coral or other organic-made limestone, and filling the depressions as fast as made, much appealed to in explanations of subsidence, has not produced the troughs; for filled depressions are not the kind under consideration. Moreover, the areas are out of the reach of continental sediments, and too large and deep to come within the range of possibilities of organic sedimentation or accumulation. The existence of the troughs is sufficient proof of this. The deep troughs of the West Indian and adjoining seas are in a region of abundant pelagic and sea-border life, and yet the marvel-

[1] In the Arctic seas, going north from the Scandinavian plateau, the water deepens north of the latitude of Iceland, between Greenland and Spitzbergen, to 2,000 fathoms, and farther north to 2,650 fathoms, in the longitude nearly of Greenwich; and it is probable that the 2000-fathom area extends over the region of the North Pole. The continents of Europe (with Asia probably) and North America are proved, by the shallow soundings over the adjoining Arctic seas and the islands or emerged land, to extend to about 82½° N., which is about 450 miles from the pole.

lous depths exist. And the depths of the open oceans are no less without explanation. Those close by the Bahamas, extending down to sixteen and eighteen thousand feet, are evidence of great subsidence from some cause; and the coral reefs for some reason have manifestly kept themselves at the surface in spite of it.

3. If superficially acting causes are insufficient, we are led to look deeper, to the sources of the earth's energies, or its interior agencies of development, to which the comprehensive system in its structure and physiognomy points. Whatever there is of system in the greater feature-lines, whether marked in troughs or in mountain chains or island ranges, must come primarily from systematic work within. The work may have been manifested in long lines of flexures or fractures as steps in the process, but the conditions which gave directions to the lines left them subject to local causes of variation, and between the two agencies the resulting physiognomy has been evolved.

We have from the Pacific area one observation of a volcanic nature bearing on the comprehensiveness of the system of feature-lines in the oceans; and although I have already referred to it, I here reproduce the facts for use in this place.

If the ranges of volcanic islands were, in their origin, lines of fissures as a result of comprehensive movements, the lines should continue to be the courses of planes of weakness in the earth's crust. The New Zealand line, including the Kermadec Islands and the Tongan group, has been pointed to as one of these lines, and one of great prominence, since it is the chief northeastward range of the broad Pacific, and nearly axial to the ocean. The series of volcanoes along the axis of New Zealand is in the same line. It was noticed, at the Tarawera eruption of 1883, that *four or five days after* the outbreak, and three after it had subsided, White Island, in the Bay of Plenty, at the north end of the New Zealand series, became unusually active; and *two months later* there

was a violent eruption in the Tonga group, on the Island of Niuafou. The close relation in time of the latter to the New Zealand eruption is referred to by Mr. C. Trotter, in "Nature" of Dec. 7, 1886.[1] May it not be that these disturbances were due to a slight shifting or movement along a series of old planes of fractures, successively from south to north, and hence that even now changes of level may take place through the same comprehensive cause that determined the existence of the earth's feature-lines? Owing to the long distance of the Tonga group from New Zealand, an affirmative reply to the question cannot be positively made; but there is probability enough to give great interest to this branch of geological inquiry.

[1] American Journal of Science, 1887, xxxiii. 311.

Part Fourth.

DENUDATION OF VOLCANIC ISLANDS; ITS AMOUNT A MARK OF AGE.

SINCE the evidence from denudation of the lapse of time is, as already shown, a subject of much geological interest, and one discussed at length in the author's "Expedition Geological Report," some facts and conclusions are here cited from it, especially those with regard to the island of Tahiti, of the Society Group, and the Hawaiian Islands.

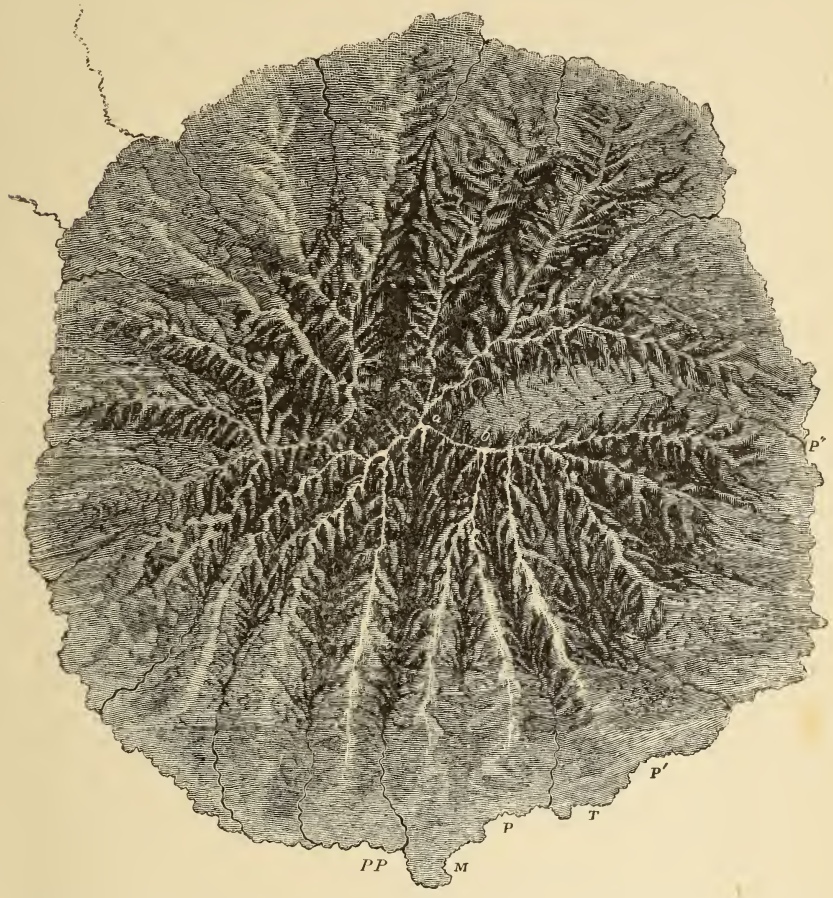
The island of Tahiti has nearly the shape, as regards outline, of the figure 8, and was once a twin of volcanoes. Only the northern and larger of the two peninsulas is often visited, and to that the following remarks refer. It was originally a gently sloping cone of the type represented by the Hawaiian volcanoes; for its beds of lavas, as seen in the sides of the valleys, slope at a small angle toward the shores; mostly 3° to 10° — varying in some parts to 15° — on the north and west sides, where the author's examinations were made. Supposing the mean slope to be 8°, the height above the sea-level of the original cone — the diameter of the island being twenty miles — would have been nearly seventy-five hundred feet. It probably much exceeded this; for the greatest height at the present time, according to an imperfect measurement made by Lieut. W. M. Walker, U. S. N., of the Wilkes Exploring Expedition (who took as a base a line measured on the coral reef near Matavai), is about seven thousand feet.

The old cone is now a dissected mountain; the dissector was running water. Valleys cut profoundly into its sides and lay bare the centre to a depth of from two thousand to nearly four thousand feet (by estimate) below the existing summit; and the deep valleys crowd on one another, owing to the extent of the erosion.

The topographic features of the island are shown on the accompanying map. This map is a copy in the main of that in Captain Wilkes's "Narrative" of the Expedition; — in the main, because changes have been made by the author, removing some of the imperfections introduced by the art of the map-maker or engraver and his want of knowledge of the region. This liberty would not have been taken, were it not that part of the map was originally from a sketch by the author, communicated to the Hydrographic Department of the Expedition. This sketch comprised the northern third of the island, from the centre outward, between the Papenoo and Punaavia valleys, and was prepared from personal observations in the valleys of the region, obtained on an ascent of Mount Aorai, one of the two highest peaks, but without a proper survey beyond a few bearings. Being the only person of the Expedition who made the ascent, no other one had the opportunity for so comprehensive a view of the ridges and valleys of that part of the island. Of the central peaks, the highest, at *a* on the map, made seven thousand feet in height by Lieutenant Walker's measurement, is called Orohena; the next highest, about five hundred feet lower, at *b*, is the one called Aorai.

The island in its present condition, as the map shows, is an admirable model of a deeply denuded or water-sculptured mountain-cone. To appreciate the precise conditions under which the denudation went forward, it has to be borne in mind that the waters from the rains and clouds are most abundant about the summits and higher portion of the

island, and are there perpetually at work. In these upper parts, therefore, or above fifteen hundred feet, forests and shrubbery cover the ridges and valleys wherever there is a foothold; but toward the coast, or below a level of one



Map of Tahiti, the coral-reefs excluded; the lower side is the northern, or that toward the equator: PP, village of Papenoö; M, of Matavai; P, of Papaua; T, of Toanoa; P′, of Papieti, the largest; P″, of Punaavia. The valleys are named from the villages on the coast at their termination.

thousand to fifteen hundred feet, the slopes, down to the grove-clad border-plain of the island, are grass-covered and look bare in the distant view.

The following are the features due to the erosion: —

1. The ridges and valleys are arranged nearly radially.

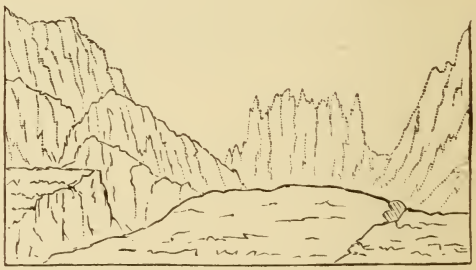
2. The highest peaks are about the centre.

3. The valleys terminate for the most part near the sea-level instead of extending deeply beneath it, as is proved by the fact that the outline of the island is nearly even, instead of being indented with deep bays.

4. The larger of these valleys abut at their heads against the central peaks in lofty precipices, — precipices of two to nearly four thousand feet. Some of the larger valleys are widest at the centre of the island and terminate under the peaks in vast amphitheatres.

5. The ridges toward the borders of the island are somewhat broad-backed, but over the interior very narrow. Above an elevation of three thousand feet or so (as I found in my ascent), the top edge of the ridges for much of the way is but three or four feet wide, — too thin to be represented on a map of so small a scale as the above; and in some spots it diminishes to a foot, and even, at times, to a thin edge of bare rock; and from the crest the declivities either side pitch off steeply one to two thousand feet.

6. Within a mile or two of the central peaks erosion has reduced the height of some of the narrow ridges a thousand feet or more, or still further lowered and thinned them until dwindled to a mere pinnacled wall at the base of the peaks. A view of a portion of one of these thinned-down ridges (called, on the island, the Crown) is here introduced. The ascent of one of the highest peaks is possible only along a ridge that has kept unbroken its connection with the summit, and an experienced guide is needed to make sure of the right and safe way.



THE "CROWN" AT THE HEAD OF THE PAPIETE VALLEY.

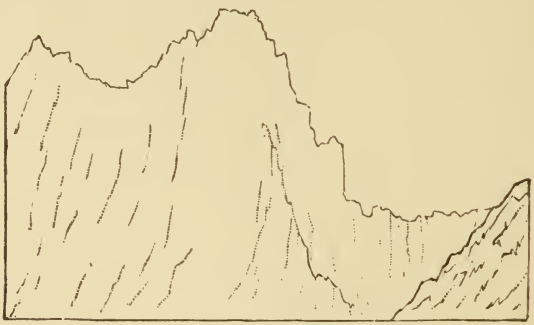
Some incidents connected with the author's ascent of Aorai will make the facts better appreciated :[1] —

"We commenced the ascent by the ridge on the west side of the Matavai Valley, and, by the skilfulness of our guide, were generally able to keep the elevated parts of the ridge without descending into the deep valleys which bordered our path. An occasional descent and a climb on the opposite side of the valley were undertaken; and although the sides were nearly perpendicular, it was accomplished without much difficulty, by clinging from tree to tree, with the assistance of ropes, at times, where the mural front was otherwise impassable. By noon of the second day we had reached an elevation of five thousand feet, and stood on an area twelve feet square, the summit of an isolated crest in the ridge on which we were travelling. To the east we looked down two thousand feet into the Matavai valley; to the west a thousand feet into a branch of the Papaua valley, the slopes either way being from sixty to eighty degrees, or within thirty degrees of perpendicular. On the

[1] On the excursion I had with me only two Tahitians. The ascent was made after Captain Wilkes had left Tahiti with his vessel, the "Vincennes," and hence the mistaken statement in his "Narrative" that I was accompanied by others of the expedition.

Very few of the natives then living had ever been to the summit of this mountain, and great difficulty was found in obtaining a guide acquainted with the route. Paths led as far as the Feiis, or mountain plantains, an elevation of one thousand to fifteen hundred feet; but beyond this the tops of the ridges are mostly covered with a wiry brake (Gleichenium), which grows in some places to a height of ten feet, and is almost impenetrable. In order to pass through it, we had to break it down by throwing our bodies at full length upon it or by diving into it; or, where too high to admit of this mode of progress, we had recourse to burrowing, pushing aside and breaking off its crowded stems, and thus we dug our way for rods. In addition to the brake, the shrubbery often formed a dense thicket, impassable except with a hatchet. These obstacles made progress slow; and without a native to lead the way, the jaunt, difficult in itself, would have been quite impracticable in the five days allotted to it. Another discomfort on the route was the want of water, which, after a few days of dry weather, is seldom to be found in the valleys near the summit. A traveller in the mountains of Tahiti should go well provided against this inconvenience. We found dew from the leaves a great luxury; and the news that water had been found in a valley created a sensation of pleasure scarcely describable.

side of our ascent, and beyond, on the opposite side, our peak was united with the adjoining summit by a thin ridge, reached by a steep descent of three hundred feet. This ridge was described, by our natives, as no wider at top than a man's arm; and a fog coming on, they refused to attempt it that day. The next morning being clear, we pursued our course. For a hundred rods the ridge on which we walked was two to four feet wide, and from it we looked down on either side a thousand feet or more of almost perpendicular descent. Beyond this the ridge continued narrow, though less dangerous, until we approached the high peak of Aorai. This peak had appeared to be conical and equally accessible on different sides; but it proved to have but one place of approach, and that along a wall with precipices of two to three thousand feet, and seldom exceeding two feet in width at top. In one place we sat on it as on the back of a horse, — for it was no wider, — and pushed ourselves along till we reached a spot where its width was doubled to two feet, and, numerous bushes again affording us some security, we dared to walk erect. We at last stood perched on the sum-



PEAKS OF OROHENA, WITH PITOHITI TO THE LEFT.
(As seen from the summit of Aorai.)

mit edge, not six feet broad. The ridge continued beyond for a short distance, with the same sharp, knife-edge character, and was then broken off by the Punaavia valley. Our height afforded a near view of Orohena; it was sepa-

rated from us only by the valley of Matavai, from whose profound depths it rose with nearly erect sides. The peak is saddle-shaped, and the northern of the two points is called Pitohiti.[1] These summits, and the ridge which stretches from them toward Matavai, intercepted the view to the southward. In other directions the rapid succession of gorge and ridge that characterizes Tahitian scenery was open before us. At the western foot of Aorai appeared the Crown. Beyond it extended the Punaavia valley, the only level spot in sight; and far away, in the same direction, steep ridges, rising behind one another with jagged outline, stood against the western horizon. To the north, deep valleys gorge the country, with narrow precipitous ridges between; and these melt away into ridgy hills and valleys, and finally into the palm-covered plains bordering the sea.

"On the descent we followed the western side of the Papaua valley, along a narrow ridge, such as has been described, only two or three feet wide at top, with precipices either side of not less than a thousand feet. Proceeding thus for two hours, using the bushes as a kind of balustrade though occasionally startled by a slip of the foot one side or the other; our path suddenly narrowed to a mere edge of naked rock, and, moreover, the ridge was inclined a little to the east, like a tottering wall. Taking the upper side of the sloping wall, and trusting our feet to the bushes while clinging to the rocks above, carefully dividing our weight lest we should precipitate the rocks and ourselves to the depths below. we continued on till we came to an abrupt break in the ridge of twenty feet, half of which was perpendicular. By means of ropes doubled around the rocks above, we in turn let ourselves down, and soon reached again a width of three feet, where we could walk in safety. Two hours more at last brought us to slopes and ridges where we could breathe freely."

[1] The sketch on page 378 is from the author's note-book of 1839; it was not used in his Report.

The peculiarities here described characterize all parts of the island. Toward the high peaks of the interior the ridges which radiate from or connect with them become mere mountain walls with inaccessible slopes, and the valleys are from one to three thousand feet in depth. The central peaks themselves have the same wall-like character. It is thus with Orohena and Pitohiti, as well as Aorai; and owing to the sharpness of the summit edge, rather than the steepness of the ascent, Orohena is said to be quite inaccessible.

Now contrast this dissected volcanic mountain with those of the Hawaiian Islands:[1] —

"Mount Loa, whose sides are still flooded with lavas at intervals, has but one or two streamlets over all its slopes, and the surface has none of the deep valleys common about other summits. Volcanic outflows have kept its surface essentially even, and by its continuation to this time, the waters have had scarcely a chance to make a beginning in denudation. Mount Kea, which has been extinct for a long period, has a succession of valleys on its windward or rainy side which are several hundred feet deep at the coast and gradually diminish upward, extending in general about one half or two thirds of the way to the summit. But to westward it has dry declivities, which are comparatively even at the base, with little running water. A direct connection is thus evinced between a windward exposure and the existence of valleys. And we observe also that the time since volcanic action ceased is approximately or relatively indicated; for it has been long enough for the valleys to have advanced only part-way to the summit. Degradation from running water would of course commence on such slopes, — that is, the windward slopes, — at the foot of the mountain, where the waters are necessarily more abundant and more powerful in denud-

[1] Pages 379–392: "On the Origin of the Valleys and Ridges of the Pacific Islands."

ing action, in consequence of their gradual accumulation on their descent.

"Haleakala, or eastern Maui, offers the same facts as Mount Kea, indicating the same relation between the features of the surface and the climate of the different sides of the island. On eastern Oahu the valleys are much more extensive; yet still the slopes of the original cone may be in part distinguished. And thus we are gradually led to Kauai, where the valleys are very profound and the former slopes can hardly be made out. The facts are so progressive in character that all must be equally attributed to the running water of the land. The valleys of Mount Kea, extending some thousands of feet up its sides, sustain us in saying that time only is required for explaining the existence of any similar valleys in the Pacific."

The Report adds the following in explanation: —

"Suppose a mountain sloping around like a volcanic dome of the Pacific. The excavating power at work proceeds from the rains or condensed vapor, and depends upon the amount of water and rapidity of slope. The transporting force of flowing water as shown by Hopkins increases as the sixth power of the velocity, — double the velocity giving sixty-four times the transporting power. Hence, if the slopes are steep, the water gathering into rills excavates so rapidly that every growing streamlet ploughs out a gorge or furrow; and consequently the number of separate gorges is very large, and their sizes comparatively small, though of great depth, — a condition well illustrated on northeastern Maui. The excavation above, for a while, is feeble in amount; the waters accumulate as they descend, causing, especially during the rainy seasons, the denudation to be greatest below, and in this part the gorge or valley most rapidly forms. In its progress it enlarges from below upward, though also increasing above, while at the same time the many tributaries are making lateral branches. Toward the foot of the mountain the

excavating power gradually ceases when the stream has no longer in this part a rapid descent, — that is, whenever the slope is not above a few feet to the mile. The stream then consists of two parts, the torrent of the mountains and the slower waters below, and the latter is gradually lengthening at the expense of the former.

"After the lower waters have nearly ceased excavation, a new process commences in this part, — that of widening the valley. The stream, which here effects little change at low water, is flooded in certain seasons, and the abundant waters act *laterally* against the inclosing rocks. Gradually, through this undermining and denuding operation, the narrow bed becomes a flat strip of land between lofty precipices, through which, in the rainy seasons, the streamlet flows in a winding course. The streamlet, after the flat bottom of the valley is made, deposits detritus on its banks, which in some places so accumulates as to prevent an overflow of the banks by any ordinary freshet. Such is the origin of the deep channels with a riband of land at bottom that cut through the dividing plain of Oahu, and which are common toward the shores of many of the Pacific islands.

"The torrent part of the stream, as it goes on excavating is gradually becoming more and more steep. The rock-material operated upon consists of layers of unequal hardness, varying but little from horizontality while dipping toward the sea, and this occasions the formation of cascades. Whenever a softer layer wears more rapidly than one above, it causes an abrupt fall in the stream: it may be at first but a few feet in height; but the process begun, it goes on with accumulating power. The descending waters in this spot add their whole weight, as well as a greatly increased velocity, to their ordinary force; and the excavation below goes on rapidly, removing even the harder layers. The consequences are, a fall of increasing height, and a basin-like excavation directly beneath the fall. Often, for a short distance below,

the stream moves quietly before rushing again on its torrent course; and when this result is attained by the action, the height of the fall has nearly reached its limit so far as excavation below is concerned, though it may continue to increase from the gradual wear and removal of the rocks over which it descends.

"As the gorge increases in steepness, the excavations above deepen rapidly, — the more rapid descent more than compensating, it may be, for any difference in the amount of water. Moreover, as the rains are generally most frequent at the very summits, the rills in this part are kept in almost constant action through the year, while a few miles nearer the sea they are often dried up or absorbed among the cavernous rocks. The denudation is consequently at all times great about the higher parts of the valley, especially after the slopes have become steep by previous degradation, and finally an abrupt precipice forms its head.

"The waters descending the ridges either side of the valley, or gorge, are also removing these barriers between adjacent valleys, and are producing, as a *first* effect, a thinning of the ridge at summit to a mere edge; and as a *second*, its partial or entire removal, so that the two valleys may at last be separated only by a low wall, or even terminate in a common head, — *a wide amphitheatre enclosed by the lofty mountains.* In one case the ridge between the two valleys, which toward the shores of the island has rather a broad back, high up in the region of mists and frequent rains becomes a narrow wall, and thus connects with the central summit. In the other, the ridge finally terminates abruptly, and a deep valley separates it from the main mountain.

"We have here to remember that these mountain streams at times increase their violence a million-fold when the rains swell the waters to a flood. There is everything favorable for degradation which can exist in a land of perpetual summer; and there is a full balance against the frosts of colder

regions in the exuberance of vegetable life, since it occasions rapid decomposition of the surface, covering even the face of a precipice with a thick layer of altered rock, and with spots of soil wherever there is a chink or shelf for its lodgment. The traveller ascending a valley on one of these islands on a summer day, when the streams are reduced to a mere rill which half the time burrows out of sight, seeing the rich foliage around, vines and flowers in profusion covering the declivities and festooning the trees, and observing scarcely a bare rock or stone excepting a few, it may be, along the bottom of the gorge, might naturally question with respect to the agents which had channelled the lofty mountains to their base. But though silent, the agents are still on every hand at work: decomposition is in slow but constant progress; and the percolating waters are acting internally if not at the surface. Moreover, at another season, he would find the scene changed to one of noisy waters careering over rocks and plunging down heights with frightful velocity. Then the power of the stream would not be disputed."

The Report concludes with the remark: —

"With literal truth, therefore, we may speak of the valleys of the Pacific islands as the furrowings of time, and read in them marks of age. We learn from such facts how completely the features of an island may be obliterated by this simple process; that even a cluster of peaks like Orohena, Pitohiti and Aorai of Tahiti may be derived from a simple volcanic dome or cone. Mount Loa contains within itself the material from which an island like Tahiti might be modelled that should have nearly twice its height and four times the geographical extent."

Great denudation on the *leeward* side of an island is an exception to the usual rule. It is a consequence, on Oahu, of the sharp-crested twenty-mile precipice facing to the *windward*.[1] The trade-winds become chilled on striking the

[1] See page 282 and Map on Plate XIII.

summit of the precipice, and ready, therefore, to drop their moisture; but as they are moving on, they get beyond the summit before much of the moisture falls, and so the *leeward* slopes receive the water. In the upper part of the Nuuanu valley, within two miles of the *pali*, one hundred and thirty-two inches of rain fall a year, and nearly one hundred inches less than this at Honolulu, although brief sprinklings occur almost daily over the city. Konahuanui and Lanihuli, in the view from Honolulu, are generally under clouds; but from Kaneohe, they are usually uncovered.

A nearly similar condition exists in West Maui, owing to the thinness of the rocky walls at the head of its great valleys. Very broad valleys are consequently made there on the leeward side, as in Oahu, as shown on Plate XII.; but these valleys end below rather abruptly in a slender gulch, which may be, for the most of the year, a "dry run;" the excessively dry and hot airs of the lower plains carrying away the water and supplying almost none.

This subject of denudation and the making of valleys is so well illustrated, also, by the facts which the author observed in New South Wales in the interval between his visit to Tahiti in 1839 and to the Hawaiian Islands in 1840, that a few additional pages are here cited from his Report.[1]

"The great depth, extent, and number of the valleys of New South Wales are calculated to excite wonder and perplex us much in the study of their origin. In some of these sandstone regions the gorges intersect the country in endless succession, and are alike in their inaccessible precipices of one, two, or three thousand feet. They are deep gulfs, with walled sides, composed of horizontal layers of sandstone. These layers seem once to have been continuous; and what is the force which has thus channelled the mountain struc-

[1] Pages 526–532: on "Degradation of the Rocks of New South Wales and Formation of the Valleys."

ture? Are they 'stupendous rents in the bosom of the earth?'[1] Are they regions of subsidence? Can it be that they were never filled, but were depressions left between the heaps of accumulating sediment that constitute the sandstone, which depressions were afterwards enlarged by the sea during the elevations of the land?[2] Or may we adopt the 'preposterous' idea that simple running water has been the agent; and if so, was it fresh water or that of the ocean?

"The forms of these valleys are as remarkable as their extent. Major Mitchell states that Cox River rises in the vale of Clywd, 2,150 feet above the sea, and leaves this expanded basin through a gorge 2,200 yards wide, flanked on each side by rocks of horizontally stratified sandstone 800 feet high: here it joins the Warragamba. Some of its tributaries rise at a height of 3,500 feet above the sea, and the ravines they occupy cover an area of 1,212 miles. From this he calculates that *one hundred and thirty-four cubic miles* of stone have been removed from the valley of the Cox.[3]

"The facts observed by us are sufficient to substantiate the general conclusion of Major Mitchell. The Kangaroo valley is another example of a valley two to three miles in width, and a thousand to eighteen hundred feet deep, opening outward through a comparatively narrow gap; and by a rough calculation from our own examinations and the map of Major Mitchell, the amount of rock necessary to fill the valley is equivalent to a rectangular ridge twelve miles long, two miles wide, and two thousand feet deep. This is but a small example, however, compared with those of the interior. Mr. Darwin remarks upon this peculiarity of form, — their extent and width and many branches, yet narrow openings at their lower extremity; and he observes that the same is the character of the bays along the coast.

[1] Count Strzelecki, in his "New South Wales and Van Diemen's Land," p. 57.

[2] Darwin, in his "Volcanic Islands," p. 137.

[3] Mitchell's Expedition into Australia, ii. 352.

"The idea that running water was the agent in these operations appears not so 'preposterous' to us as it was deemed by Mr. Darwin, and we think that Major Mitchell was right in attributing the effects to this cause. The extent of the results is certainly no difficulty with one who admits time to be an element which a geologist has indefinitely at command. We need but refer to the facts from the Pacific islands to show that New Holland, after all, is not the most remarkable land in the world for valleys of denudation.

"We should consider that the rock material is far more yielding than that of basaltic Tahiti. Indeed the whole rock, from the uppermost layer to the deposits below the coal, is remarkably fragile, considering the age of the deposits, crumbling readily, and often breaking without difficulty between the fingers; and besides it is much fissured. Even the harder fossiliferous Wollongong rock, as has been described, falls to pieces of itself when exposed to the air. Moreover, there are occasionally clayey or argillaceous layers which are still softer; and many of those of the coal formation are not firmer than the material of a common clay-bank. The denudation of such material requires no preparatory decomposition, as with many igneous rocks, but takes place from wear alone, and with but slight force in the agent.

"It is obvious, for the same reason, that the material carried off by denudation ought not to appear in fragments through the lower country. A short journey along a rapid stream would reduce even large masses to powder. The plains of the Kangaroo valley are covered in places with basaltic pebbles or bowlders; but the sandstone, which is the prevailing rock along the bed of the stream and in the enclosing hills, has scarcely a representative pebble in the debris. The sandstone blocks are worn to sand and earth by the torrents, while the harder basalt is slowly rounded. On the plains of Puenbuen similar facts were apparent. The

hills contain sandstone and basalt, but only the latter appears as bowlders or pebbles over the plains, or along the streams below.

"This Sydney sandstone does not even require running water to promote degradation. In many caverns along cliffs, the rock gradually falls to powder by a species of efflorescence. There are numerous instances of this along the coves of Port Jackson, where the crystallization of the saline spray reduces the rock to its original sand; and in the interior of the country there are large caves, formed apparently by this same process, though probably from the crystallization of nitrates. Near Puenbuen, these caves are from six to twenty feet deep, and from four to forty long. The roof is arched, and appears to be constantly crumbling, while the bottom is covered with a fine, dry, ash-like sand, into which the feet sink several inches. The same operation is going on along the summits of the Illawarra range; and one huge block was found so hollowed out in this way as to be a mere shell, which sounded under the hammer like a metallic vessel.

"These various facts bring before us some idea of the yielding nature of the rock which the waters have to contend with in the denudation of this country, and they also illustrate the various processes at work. We allude to a single other mode of degradation before passing: it is the action of growing trees and their roots, both in opening fissures and tumbling blocks down the precipices. It is a cause influencing very decidedly the characters of cliffs, and at the same time preparing the rock for decomposition and wear.

"The credibility of the view here favored is further sustained by the character of the streams. The great extent of the floods and the rapid rise of the rivers attending them have been alluded to. The stream of the Kangaroo Grounds, when visited by the writer, was a mere brook,

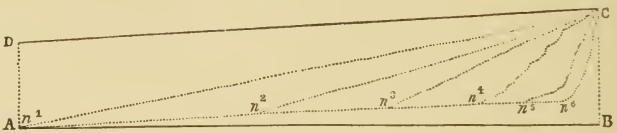
fordable in any part; and it flowed along with quiet murmurings. But a few weeks before the brook was a river thirty feet deep, driving on in a broad torrent, and flooding the valley. If, as has been shown, the transporting power of running water increases as the sixth power of the velocity, and a stream of fifteen miles an hour has more than ten times the transporting power of one moving ten miles an hour, and more than a million times that of a stream of two miles an hour, we can comprehend how inadequate must be the conceptions of this force which we derive from viewing the streams at low water.

"This rise in the Kangaroo Grounds is an index of what takes place every few years over the whole country. Surprise at the amount of degradation subsides before such facts; we rather wonder that sandstones so soft and fragile, which have been exposed probably from the Oolitic period, still cover the surface to so great an extent as they do at the present time.

"Mr. Darwin derived his principal argument against the hypothesis of denudation from the forms of the valleys, — their width, extent, and ramifications, and yet *narrow* embouchures. But we find on consideration that this form is a necessary result of the mode of denudation under the circumstances existing. In the account of the valleys of the Pacific islands it has been shown that the gorges change their character where the slopes become quite gradual, from a narrow defile with convergent sides to a broad channel with vertical walls and flat bottom. The same cause should produce a like effect in Australia. A stream, in making a descent of two or three thousand feet from the higher summits to the level of the sea, gradually deepens its bed by wear. Since the waters are increasing in quantity from various sources as they flow onward, this deepening of the gorge should be most rapid at its lower extremity; and it would continue in progress until the bed in that part be-

came so low or gradual in slope, that the waters had lost to a large degree their eroding force, and any excavation at bottom was made up by the material deposited along its course. This fact determines a permanent height for the bottom of the lower valley. As the stream continues its wearing action in the same manner, the lower valley is gradually prolonged upward, retaining nearly the same slope at bottom (one or two feet to the mile); consequently the steeper portion of the gorge is at the same rate becoming shorter and still steeper. Thus the head of the stream may finally become a series of cascades, or, as happens at times in the Pacific, it may be reduced mostly to a single cascade of a thousand feet or more.

"The progress of this change may be better understood from the following diagram: —



A B C D is the rock to be cut through by the stream. Suppose denudation to produce first the course C n^1. The stream is filled, as is commonly the case, by lateral channels and rills down the sides of the gorge, as well as by the main source; and the amount or depth of water is thus in constant increase, as it flows onward. Denudation is consequently most rapid the farthest from the head, or toward n^1; the valley, therefore, increases in depth in this part till the slope has become so gentle here as to counterbalance the greater amount of water, at which point the bottom of the valley ceases to increase in depth; in this condition n^1 n^2 becomes the bottom of the lower valley, and C n^2 the steeper portion above it. In the same manner the valley bottom continues to prolong at nearly the same slope, and C n^3, C n^4, C n^5 become successively the course of the stream

descending into it. And even $C n^6$ is not an exaggeration of possibilities, for many examples of it are met with.

"But the results explained are but a part of the actual course of things in these regions of horizontally stratified rock. As on Oahu and elsewhere, when the denudation at bottom has reached its limit, the waters exert but little degrading power except during floods, and this takes place by the sides of the overflowing stream; at the same time depositions of detritus take place along its banks. The result is that the rocks bounding the valley are worn away below, and are often undermined; the valley widens at bottom to a flat plain, while the enclosing wall by the process becomes nearly vertical. A narrow riband of land between high precipices of rock is therefore a necessary result of the action.

"Degradation still continues along the upper or steep part of the main stream, and also along the many streamlets and rills pouring down the valley's sides; and in each of these streamlets there is a tendency to produce below a flat-bottomed valley. The consequence is that they increase the width and extent of the main valley-plain; for whenever they become thus flat-bottomed, they contribute to its lateral enlargement.

"At the same time the bluffs at the lower extremity, or embouchure, of the main valley remain without much change, since the denudation is mostly confined to the vicinity of the streamlets alluded to, and these streamlets are most abundant above, they being produced and fed mainly by the rains in the higher parts of the mountains. It is natural enough, therefore, that the valleys should not only become flat below and precipitous in their sides, but also that they should widen least at their lower extremity. We see, consequently, no necessity of appealing to any other cause than that of running water to account for the most stupendous results in Australia.

"It has been supposed that the sea has been largely concerned in the denudation which has produced the Australian valleys. We find no reason for attributing any of the valleys to this source, although it is possible that some modifications may thus have resulted. The facts at Port Jackson are a sufficient reply on this point. The cliffs of the estuary actually undergo very little change from the action of its waters, and are far more altered by the mode of efflorescence described and by rills of running water; and such action as is exerted tends to remove headlands instead of deepening the coves.

"The proper action of the sea is seen in the character of the sandstone shores of East Australia, and especially in the wide platform of rock below high-tide level lying at the foot of lofty cliffs. This platform is a simple projection of the lower layer of the cliff; from above it, the waves have carried away the rock to a distance inward of fifty to one hundred and fifty yards. At Port Jackson, Newcastle, and Wollongong Point are fine exhibitions of it."

NOTE ON HAWAIIAN PRONUNCIATION.

The following rules comprise nearly all that is essential for correctness in the pronunciation of Hawaiian words, except on one point, — that of accentuation: —

1. Sound the vowels as in Italian, and the consonants (eight in number, *h*, *k*, *l*, *m*, *n*, *p*, *t*, *w*) as in English, except *w*, the pronunciation of which is between that of *w* and *v*.

2. Make as many syllables in a word as there are vowels. The word *Hawaii* is not an exception, although the distinction of the closing syllables might not be perceived by one unfamiliar with the spoken language. *Kau* has two syllables. *Ka-u; Kilauea* has five, *Kī'la-u-e'a;* but the second and third are nearly blended in the pronunciation.

3. Never make a syllable end with a consonant. Thus, *Ho'no-lu'lu* is right, not *Hon'o-lu'lu; Ha'le-a'ka-la*, not *Hal'e-ak'a-la*. In Hawaiian all words as well as syllables end in a vowel, and two consonants have always a vowel between them.

4. An apostrophe between two vowels implies that a *k* is dropped, and that an interruption of the voice is there required in pronunciation, — as in *Halema'uma'u*.

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University Press: John Wilson & Son, Cambridge.

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